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WORK OF R.E.

IN THE

EUROPEAN WAR. 1914-19

WATER SUPPLY.—FRANCE

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THE

WORK OF THE ROYAL ENGINEERS

IN THE

EUROPEAN WAR, 1914–19.

WATER SUPPLY.

PART I.

GENERAL DEVELOPMENT OF ORGANIZATION, PLANT AND WORKS.

PART II.

OPERATIONS.

PUBLISHED BY THE SECRETARY, R.E. INSTITUTE, CHATHAM.

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PART I.

GENERAL DEVELOPMENT OF ORGANIZATION, PLANT AND WORKS.

PART II.

OPERATIONS.

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CONTENTS.

PART I.

CHAPTER 1.—OUTLINE OF ORGANIZATION AND DEVELOPMENT.

		Page
1.	Introduction	13
2.	Investigations into Conditions in Belgium and N.E. France	14
3.	Water Supply Committee	14
4.	Barge Purification Plants	16
5.	Water Tank Companies	19
6.	Appointment of Water Supply Officers	19
7.	Power Driven Pumps	20
8.	Summary of Development up to July, 1916	20
9.	System of Carrying out Work	21
10.	Army Electrical and Mechanical Companies, R.E.	21
11.	Boring for Water	23
12.	Appointment of I.R.E.M. at G.H.Q.	23
13.	Geology	24
14.	American Water Supply Organization	26

CHAPTER 2.—STORES AND MACHINERY.

15.	General	29
16.	Piping	29
17.	Fittings	30
18.	Machinery—General	33
19.	Standardization of Types	34
20.	Ram Pumps	35
21.	Steam Pumps	37
22.	Tube Well Pumps	38
23.	Centrifugal Pumps	39
24.	Rotoplunge Pumps	41
25.	Airlift Sets	41
26.	Mobile Air Compressor Plants	42
27.	Water Lifts	42
28.	Spare Engines and Parts	43
29.	Experience in other Theatres of War	45
30.	Boring Plant	45
31.	Ashford Tube-Well Strainers	46
32.	Mechanical Filters	46

CHAPTER 3.—WORKS.

33.	General	48
34.	Water Points	48
35.	Local Water Points	50
36.	Trench Filling Points	51
37.	Purification	52
38.	Haringhe Water Works	53

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PART II

CHAPTER 1.—THE SOMME, 1916.

		Page
1.	Preparatory Measures	57
2.	Developments after the Attack	64
3.	Work of the Water Column during Battle	67

CHAPTER 2. GERMAN WITHDRAWAL TO HINDENBURG LINE, ARRAS AND VIMY RIDGE.

4.	Development during Winter, 1916–1917	68
5.	Preparations for the Battle of Arras	70
6.	German Withdrawal to the Hindenburg Line	71
7.	Battle of Vimy Ridge	73

CHAPTER 3. MESSINES, PASSCHENDAELE, AND CAMBRAI, 1917.

8.	Preparation for the Battle of Messines	75
9.	Ypres—Passchendaele, 1917	76
10.	Coastal Area (Dunkerque to the River Yser)	77
11.	Ypres Area during Winter, 1917	78
12.	Battle of Cambrai, 1917	79

CHAPTER 4.—1918.

13.	German Offensive, March 21st, 1918	80
14.	Fourth Army Attack, August, 1918	81
15.	General British Advance	82
16.	Water Tank Companies during the Final Advance	84
17.	Conclusion	86

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LIST OF ILLUSTRATIONS.

PART I.

Description.	No.		Referred to on Page
Photo	I.	Verticle Triple Ram Pearn Pump	36
Photo	II.	Blackstone 7 h.p. Oil Engine	36
Photo	III.	Hayward Tyler Pump	36
Photo	IV.	Guy & Mital Single Ram Pump	36
Photo	V.	No. 1 Merryweather Valiant Pump	37
Photo	VI.	No. 2 Ditto	37
Photo	VII.	Potter Tube Well Pump	38
Photo	VIII.	Dorman-Mather & Platt Set	40
Photo	IX.	Denis-Mather & Platt Set	40
Photo	X.	Keighley-Gwynne Set	40
Photo	XI.	Roto-plunge Pump	41
Photo	XII.	Compressor Lorry — Dorman-Lacy-Hulbert Set	42
Photo	XIII.	Compressor Lorry—De Dion-Broome and Wade Set	42
Photo	XIV.	Isler Drill	45
Photo	XV.	Star Tractor Drill	45
Photo	XVI.	Drills ready for the road during 1918 advance	46
Photo	XVII.	Horse Water-point	50
Photo	XVIII.	Filling Water Bottles	50
Photo	XIX.	Typical Water Point in Flanders	50
Photo	XX.	Haringhe Water Works—Panoramic View	53
Photo	XXI.	,, ,, ,, Mechanical Filtering Plant	53
Photo	XXII.	,, ,, ,, Sedimentation Tanks	54
Photo	XXIII.	,, ,, ,, Kelvin 60 h.p. Petrol Engine in Main Pump House	54
Photo	XXIV.	,, ,, ,, Auxiliary Steam Pumps	54
Photo	XXV.	,, ,, ,, View of Intake	54
Plate	I.	Geological Sketch Map	25
Plate	II.	Geological Section—Ostend to Peronne	25
Plate	III.	American W.S. Organization—Chart	26
Plate	IV.	C.I. Double Collar for 4-inch Steel Pipe	32
Plate	V.	Water Bottle Filler	32
Plate	VI.	Notice Board for marking Pipe Lines	32
Plate	VII.	Water Tank of Wood, Wire Mesh and Canvas	33
Plate	VIII.	Well-head Windlass and Frame	39
Plate	IX.	Airlift Head	42
Plate	X.	Details of Mounting of Dorman Engine and Lacy-Hulbert Compressor on 3-ton Lorry	42
Plate	XI.	Details of Mounting of Aster-Wembley Engine and Broome & Wade Compressor	42

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Description	No.		Referred to on Page
Plate	XII.	Petter " Junior " Belt Pumping Set	43
Plate	XIII.	Output Curves for Belt Pumps	43
Plate	XIV.	Well Boring Tools	46
Plate	XV.	Section of Deep Well Bore at Cunewele	46
Plate	XVI.	Ashford Filter Tube	46
Plate	XVII.	Method of using 16 ft. × 16 ft. Tarpaulin for Water Transport	48
Plate	XVIII.	Portable Frame for Canvas Water Tanks	49
Plate	XIX.	Reservoir to hold 50,000 gallons	49
Plate	XX.	Sheet Iron Horse Trough	50
Plate	XXI.	Water Cart Filling Points off Main Roads	50
Plate	XXII.	Standard Water Point for Hand Pump and Standpipe	50
Plate	XXIII.	Protective Frame for Lift and Force Pump	50
Plate	XXIV.	Plan of Trench Water Point	51
Plate	XXV.	Section of Ditto	51
Plate	XXVI.	Chlorinating Set for Bottle Filling	52
Plate	XXVII.	Non-automatic " Poste de Javellisation "	52
Plate	XXVIII.	" Eau de Javel "—Automatic Supply	52
Plate	XXIX. & XXIX.A.	Adjustment Tables for constant-feed Chlorinator	53
Plate	XXX.	Portable Alum Sedimentation and Chlorinating Installation	53
Plate	XXXI.	Adjustable Constant Feed Chlorinator	53
Plate	XXXII.	Haringhe Water Works.	53
Map	A.	Map of Water Supply—Tournai, 1/100,000	14
Map	B.	Key Plan of Bores and Thanet Sand Levels—Second Army, 1917-18	46

PART II.

Plate	I.	Diagram of Water Supply Systems, Fourth Army, November, 1916	65
Plate	II.	,, Proposed Forward Extensions	65
Plate	II.A.	Fourth Army Water Supply	66
Plate	III.	,, ,, Water Column—Graph.	67
Plate	IV.	Third Army Advance Water Supply—Index Map, March, 1917	70
Plate	V.	Second Army—Ditto, May, 1917	75
Plate	VI.	,, ,, September, 1917	77
Plate	VII.	Wells.—Type sunk by 23rd Field Company, R.E., at Le Clipon Camp—July, 1917	78
Plate	VIII.	Arrangement and details of Tanks fitted in sea-going barges	78
Plate	IX.	Illustrates type of filter erected at Dickebusche Lake and Ypres Moat	79
Photo	I.	Underground Pumping Station, Gavrelle	74
Photo	II.	Exterior, Boosting Station near Elverdinghe	76
Photo	III.	Interior, ditto	76
Photo	IV.	Boesinghe Water Point	76
Photo	V.	Light Railway Water Point	77
Photo	VI.	Dam in Ypres Canal	77
Photo	VII. & VIII.	Sedimentation Tanks under construction Ypres Water-works	77
Photo	IX.	Laying 6-inch Pipe	79

Digitized by Google

Description	No.		Referred to on Page
Photo	X.	Water Point worked by Compressor Lorry at La Vicogne	83
Photo	XI.	Water Supply Bridge at Neuville . .	87
Photo	XII.	Water Supply Bridge at Denain . .	87
Map	A.	New Water Points, Fifth Army—March–April, 1917	72
Map	B.	Part of Third and Fourth Army areas—1917–1918	73
Map	C.	Coastal area—Dunkerque to the River Yser—Summer, 1917	77
Map	D.	N.W. Europe 1/250,000 General Map .	80
Map	E.	First Army area—August, 1918 . .	81
Map	F.	Captured German Water Supply Map .	83
Map	G.	Fourth Army development, April–November, 1918	87
Map	H.	Third Army ditto. August–November, 1918	87

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Part I.

GENERAL DEVELOPMENT OF ORGANIZATION, PLANT AND WORKS.

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Chapter I.

OUTLINE OF ORGANIZATION AND DEVELOPMENT.

1. *Introduction.*—The adequate supply of water is of paramount importance in every phase of warfare. Men can fight, and continue to fight, in spite of a shortage of ammunition, for considerable periods; both men and animals can subsist for several days on a minimum supply of food, but both men and animals will break down in a few hours, and lose their spirit, condition, and power of resistance, unless they can obtain water in sufficient quantities, and of the necessary purity.

The development and evolution of the system of water supply in the B.E.F. may be thus briefly described:—

At the opening of the campaign the British Army was equipped only for the supply of water to men and animals in small quantities, from supplies available on, or just below, the surface of the ground. Accordingly, the power of location, and consequently of concentration of troops (which generally include a proportion of one animal for every three men), was greatly limited, because animals had necessarily to be located in places at which surface water was available, or they would lose condition and power of work in making long journeys to and from sources of supply.

At the close of hostilities the water supply organization and equipment had been so greatly developed and improved, that concentrations of unexampled density, and operations, could be successfully undertaken at short notice in any areas, and at the points most desirable for strategical or tactical reasons, without reference to the presence of water in or near the surface. The salient features of this development were:—

(*a*) The elaboration of water supply staff, and organization as part of R.E. duties in the field, including the compilation of Engineer intelligence, with special reference to geological conditions.

(*b*) The increase of mechanical plant, and the employment of semi-permanent and extensive systems of supply, with headworks and pipe lines.

(*c*) The use of mechanical transport for the carriage of water.

(*d*) The employment of mechanical systems for the filtration and purification of water.

(*e*) The extensive use of boring plant to render available deep-seated sources of supply.

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The following account deals with the subject of water supply in army areas only: the water supply at bases and on L. of C. is described in the volume, "Work under the Director of Works, France."

2. *Investigations into Conditions in Belgium and N.E. France.*—One of the first works undertaken in the office of the Chief Engineer, B.E.F., at G.H.Q., when the line began to be stabilized in December, 1914, was investigation of water supply services, especially those in towns and villages. These were tabulated in pamphlets; a series of maps were commenced showing the pipe systems of supply, number of wells, utilization of sources. These maps were continually amended as further information came in, and several editions were published. *Map* A is a copy of the third edition of the Tournai sheet.

The seasonal variations in Flanders were ascertained to be very great, and records were obtained of prolonged droughts in certain areas, generally in August and September, months in which military activity would be at its highest.

When these investigations were commenced the British forces were occupying a line Béthune—Ypres. The south area of the line was the region of the "Artesian" well; in the valley of the Lys and to the north of the river in Flanders only surface water was obtainable.

The results of these first investigations are briefly stated in a note that was issued early in 1915, and is printed as an Appendix at the end of this Chapter.

3. *Water Supply Committee.*—As a result of the above preliminary investigations, a Water Supply Committee was appointed in May, 1915. The Committee consisted of:—

President and Representative of the
Q.M.G. ... Col. W. A. Liddell, R.E., D.D.W., G.H.Q.
A Representative of the C.G.S.
A Representative of the D.G.M.S.

The terms of reference were:—

(*a*) To formulate the requirements of man and animals.

(*b*) To consider the technical measures likely to be required for the collection, purification, storage and distribution of water.

Recommendations of W.S. Committee. The Committee reported to the Q.M.G. on 15th June, 1915.

The conditions of supply were prescribed by the General Staff and provided for a force operating in Flanders consisting of:—

23 Infantry Divisions.
8 Corps Troops Formations.

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5 Cavalry Divisions.
2 Cavalry Corps Troops Formations.
3 Army Troops Formations.

in a rapid advance, and for periods of concentration.

The minimum scale of supply necessary to conserve strength was taken as :—

Men. On the march, one-third gallon per man per day (for limited period not exceeding three days).
Stationary, 1 gallon per man per day.

Animals. On the march, two gallons per head per day.
Stationary, three gallons per head per day.

The chief recommendations were :—

Purification. For small quantities at the Front.—By regimental water-carts.
At the rear.—By special plant installed on motor lorries and barges.

Storage. To be provided in 24 water tank barges each with a capacity of 12,000 gallons.

Distribution. To be effected by a water section added to each supply column, consisting of motor-cars fitted with tanks, and motor lorries equipped with purification and de-poisoning plant and water tanks ; and also by increasing the number of regimental water-carts.

The purification and storage barges were actually ordered by the Chief Engineer through the Director of Inland Water Transport before the Committee was formed, as it had been realized that the canals would form the only bulk supply available in Flanders.

De-poisoning apparatus was considered necessary both by the General Staff and by the War Office, owing to various rumours that were current at this time, and the reported poisoning of water by arsenic near Messines. These reports were proved later to be false, but explain why de-poisoning plant was provided.

Re-appointment of W.S. Committee. In January, 1916, the Water Supply Committee was re-appointed in view of the large increase in the number of troops in France, and of the probable scarcity of water in front of the Third Army, then in the area N. of the river Somme, and S. of Arras.

The intention to make an attack north of the Somme was made known to the Chief Engineer in January, 1916, and involved a very large concentration in the chalk area between Arras and the Somme, and also an advance across the area between the Ancre and the Escaut, which is almost devoid of surface water.

The difficulties in respect of water supply which were experienced during a very limited advance of the French in Champagne in 1915

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became known to Chief Engineer's office, and emphasized the need for very special measures.

The Committee was instructed :—

(i.) To consider whether any modifications are necessary to the original report.

(ii.) To formulate the requirements in men and animals for the Third Army, should additional water supply columns be required.

Recommendations of Committee. As the result of an *ad interim* report by the Committee, the War Office were asked to order the whole of the vehicles required for an additional Army Water Column similar to that already ordered.

The Committee reported on the 26th February, 1916, as follows :—

Summary of measures proposed for the Water Supply of the Third and Fourth Armies during an advance.

(*a*) That water supply points should be established at suitable places along the Front, and that water should be provided as far forward as possible by means of specially installed pumps and piping.

(*b*) That these supplies should be supplemented by a system of motor transport for the supply of water, approximately equivalent to four Army Water Columns of the establishment already approved ; and that the establishment of regimental water-carts should be temporarily augmented.

(*c*) In view of the difficulties in supplying some of the vehicles and plant comprised in these Army Supply Columns, the substitution for motor water-tanks (1-ton lorries) of 3-ton lorries, carrying water tanks holding 600 gallons each, and that 191 of these lorries should be supplied as soon as possible, to meet the requirements of six corps.

(*d*) In respect of the shortage of water-purification plants on motor vehicles, they recommend the distribution of the available vehicles between corps in whose areas the difficulties of water supply will be greatest.

(*e*) The temporary augmentation in six corps of the establishment of regimental water-carts, as contained in their original proposals, entailing an increase of 80 water-carts for each corps, or 480 water-carts in all. If carts of the authorised pattern are not available, water tanks should be fitted on suitable horsed carts.

(*f*) That a special staff should be appointed in each army for the organization and execution of works in connection with the supply of water to the troops.

4. *Barge Purification Plants.*—Six barge purifying plants with

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storage barges were already on order from England at the time the Committee's first report was made. These plants were originally under the control of the Inland Water Transport, and passed to the D.G.T. on the formation of the Transportation Directorate. They were located as desired from time to time by the Q.M.G.

The composition of each unit was as follows :—

The filtration barge itself with a capacity of 4,000 g.p.h. A barge for the storage of the " heavy " chemicals (14 days' supply). Four tank barges, each affording a storage of about 13,000 gallons.

Three types of plant were represented on the filtration barges :—

(*a*) Ransome Ver Mehr,
(*b*) Bell Bros.,
(*c*) United Water Softeners,

but they varied only in mechanical detail, the chemical process of purification being the same in each case, viz. :—

(i.) Sedimentation and filtration through sand or equivalent material,
(ii.) Chlorination,
(iii.) Removal of excess chlorine,

the chlorination being effected with bleaching powder, and the sedimentation by the addition of alumino ferric, and, where the water required it, of lime or sodium carbonate. The filtration and purification was arranged to be a continuous process, sedimentation being obtained in the contact tanks by means of a system of baffle plates, after filtration the water being retained on board for a further period of an hour for examination, and any further treatment by means of sodium sulphite where an excess of bleaching powder may have been necessary to obtain complete sterilization.

The filtration barges were supplied with excellently equipped laboratories, and each unit was in charge of one or more fully qualified chemist officers, who exercised control on the whole process of purification from the laboratory, which was provided with an arrangement of taps from which could be drawn at any moment samples of the water in any of its stages of treatment.

Although, as circumstances proved, it was necessary for each unit to undertake only filtration and sterilization, their equipment provided for the treatment of practically every poison which it was thought the enemy might introduce into the waterways. Their preparedness for such an eventuality necessitated the holding with each unit of a large quantity of chemicals, but the mobility conferred by the fact of the units being afloat disposed of any difficulty in this respect.

These floating filtration units were placed on order early in 1915, but the fitting of the machinery in suitable barges in England and

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making alterations to meet the requirements laid down took some time. However, the first unit crossed to France in December, 1915, and the sixth arrived on the 10th of November, 1916. Whilst the course of the war did not furnish opportunity for the units to function entirely to the extent that was at first anticipated, they were almost continuously employed from the end of 1916, and in 1917—18 rendered service in back areas, on the Lys, and near Bergues, and on the Yser, which could not have been done by any other plant.

In particular might be mentioned the work of Nos. 1 and 2 units, which for a period of 22 months were employed at Jesus Farm and Fort Rompu, a few miles from Erquinghem on the river Lys, purifying water and pumping it to a pipe-line nearly five miles long supplying a large formation.

In 1916 two units were taken by sea to the Somme, and were usefully employed for several months at Froissy, fitted to a pump-line, and later one was taken to Peronne. When no longer required on the Somme both units were brought back to the northern waterways in May, 1917.

In July, 1917, when British troops occupied the Nieuport sector, where the water supplies were found insufficient for their needs, the barge units rendered considerable service, although in this case it was not possible for them to work in the Nieuport—Furnes canal, along which the water was required, owing to the proximity of the waterway to the sea, and its consequent salinity. The units therefore had to be stationed back at Bergues, their quota of water-tank barges very largely increased, and a filtered water barge service was maintained continuously from Bergues to the various points along the Nieuport—Furnes canal, at which it was required for consumption, and also to concentration camps to the Watten area.

The units too were of service to Allies. During the operations of summer, 1917, two were working for the French on the river Yser at Rousbrugge, supplying a pipe line 10—12 miles in length.

In April, 1918, when the Germans advanced across the Lys, two units stationed at Fort Rompu were captured, evacuation being rendered impossible by tactical causes. Before they were abandoned charges were placed on board, and one filtration barge was blown up, the other being partially destroyed.

All four remaining units were usefully employed to the end of the war, and after the armistice were still at work supplying water to the camps at and near Dunkerque, and to various depôts at Dunkerque and Bergues.

The barge purification plants were the precursors of similar plants ordered for Mesopotamia, and also established a precedent in the supply of potable water from canals. As far as is known, similar purification had never hitherto been attempted either in peace or war.

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5. *Water Tank Companies.*—Following on the first report of the W.S. Committee a letter was sent by the C.-in-C. to the War Office, asking for provision in the first instance of water transport and purification plant on the scale suggested by the Committee, but for a force of one corps with three divisions, and as an independent unit. In general accordance with this letter, the first two Water Tank Companies were formed as R.A.S.C. units, with attached R.A.M.C. *personnel* for supervision of purification plant.

Nos. 1 and 2 Companies each consisted of a H.Q. and three sections, the purifying plants with their *personnel* forming integral parts of the sections. In Nos. 3 and 4 Companies, which arrived during 1917, the transport and purifying sections were distinct, and the number of transport (R.A.S.C.) sections was increased to six.

The water purifying sections (R.A.M.C.), of which there were three, were supplied with an improved form of sterilizing apparatus—the Wallace and Tiernan liquid chlorine apparatus—which increased the output of a sterilizing lorry from 400 g.p.h. to over 1,000 g.p.h.

The total capacity of each of the companies was as follows :—

	Nos. 1 & 2 Companies.	Nos. 3 & 4 Companies.
Carrying capacity ..	26,650 galls.	52,500 galls.
Sterilizing	12,000 g.p.h.	18,000 g.p.h.

The work of these Companies, and the cartage of water generally by mechanical transport, formed an important feature in the development of water supply, and many references will be found to it in the account of water supply operations in Part II. (See also para. 33, ch. III.)

6. *Appointment of Water Supply Officers.*—Early in 1916, in accordance with the recommendation of the W.S. Committee, an officer was specially selected to take charge of advanced water supplies of the Third Army. His duties were mainly of an advisory nature, and he was responsible, under the Chief Engineers of Armies, for the co-ordination of the water supply preparations of the Third and Fourth Armies, and subsequently of the Somme offensive.

Later in 1916, a Water Supply officer was appointed for each Army, and was attached to the Chief Engineer of the Army. He acted as technical adviser to the Chief Engineer on all matters connected with water supply, and was charged with the regulation and issue of all water supply stores. While the appointment was officially recognized, it was not till September, 1918, that the Water Supply officer was formally included in the establishment of the Chief Engineer. Corps Water Supply officers, acting under the instructions of the Chief Engineer Corps, and in *liaison* with the W.S.O. Army, were also appointed in 1916, one of the Field Engineers on the Chief Engineer's establishment being detailed for this duty.

The above organization, with certain variations in matters of detail, continued until the armistice.

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7. *Power Driven Pumps.*—During the first 18 months of the war, there was little need for power pumps, since the First and Second Armies were operating in a country in which water was easily obtainable at or near the surface.

It was recognized, however, that to deal with large concentrations of troops and animals, or an advance over comparatively waterless country, such as the chalk plateau in front of the Third and Fourth Armies (from Arras southwards), special provision would have to be made.

The Water Supply Committee accordingly recommended, as noted in para. 3 above, that water supply points should be established at suitable places along the front, and that water should be provided as far forward as possible, by means of specially installed pumps and piping.

In 1915, eighteen power-pumping plants of various types, each to deliver about 2,000 gallons per hour, had been ordered from the War Office, together with 120 miles of 4-inch steel piping and accessories, in anticipation of general requirements on the front.

With a view to concentration of troops and animals for the Somme offensive, which was designed to take place in the summer of 1916, considerable numbers of power pumps of various types, and a large amount of material and piping, were ordered in addition by G.H.Q. in January and February, 1916. The pumps were of various capacities from 2,000 to 7,000 gallons per hour against from 200 to 350 feet head, and represented the whole available resources in England of this nature of plant at the time.

8. *Summary of Development up to July,* 1916.—It will be seen from the particulars already given that the system as evolved in anticipation of the Somme operations was generally as follows :—

(*a*) For the preparatory concentration of troops and animals, power pumps and pipe lines were installed in large numbers over the Army area to supplement existing facilities.

(*b*) For the advance, power pumps were installed as near the Front as possible, and pipe lines were laid forward to be carried on as soon as possible after an advance should take place.

(*c*) Water points at which water-carrying lorries were to fill were established near the Front.

(*d*) As soon as an advance took place, and pipe lines were carried forward, new water points were to be made at the head of the pipe lines, or at newly developed sources.

(*e*) Water Tank Companies were to come into operation after the advance, and were to form the connecting link between the water points and the regimental water-carts.

(*f*) The water carrying lorries were to use in the first place the water supply points prepared previous to the attack. As new

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water points came into action further forward, they were to use them as filling points, so keeping down the length of haul.

(*g*) An increase was made in the number of regimental water-carts.

(*h*) Only sufficient transport was available to provide water for men in advancing. No account had been taken of the requirements of animals.

The preparations up to and for the Somme operations have been dealt with at some length, as they form the precedent for the bulk of the water supply work carried out for the later offensive operations. Some particulars will now be given of the additions to the organization which were found necessary under practical test.

9. *System of carrying out Work.*—The general system of carrying out work on the Somme was as follows.

The Army Water Supply officer was responsible under the Chief Engineer Army for the allocation and distribution of pumps, engines, piping tools, and water supply stores generally. These were stocked in Army R.E. Parks, and drawn by Corps on the authority of the Army W.S. officer.

New schemes of importance were got out by the Corps Water Supply officers under the instructions of the C.E., Corps, and were submitted for approval of the C.E., Army, and for issue of stores through the Army Water Supply officer.

The installation of pumping plants, with their foundation work, and huts or emplacements, as well as of the pipe lines, reservoirs and distribution systems, was carried out by Army Troops Companies, R.E., under the C.E., Corps, also in forward areas by Field Companies under Divisional C.R.E.'s.

The Army Troops Companies were assisted by such unskilled labour for digging, carrying pipes, etc., as was necessary or available from time to time.

10. *Army Electrical and Mechanical Companies, R.E.*—The growth of water supply work due to the intense concentration of troops and animals was very rapid, and by July 1st, 1916 (the date of the opening of the Somme operations) over 100 power pumps had been installed in Fourth Army area, and almost 120 miles of water mains had been laid. As the battle progressed these figures were continually increased.

The question of the operation and maintenance of power pumps became one of great difficulty. It was obviously beyond the power of the Army Troops Companies to provide engine drivers for such a number of scattered pumping stations. It was therefore necessary to obtain men from elsewhere, and engine drivers from the infantry and other sources were attached to Army Troops Companies for the purpose. Further, the Army Troops Companies had no means

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with the personnel and transport at their disposal of giving proper supervision. Repairs and maintenance also constituted a great difficulty, since there were no workshops properly equipped for this class of work.

In order to remedy the unsatisfactory conditions which had arisen, it was found necessary to form in each Army an Electrical and Mechanical Company, R.E., whose province it would be to look after all power-pumping plant, and to form workshops for the repair of the machinery. A makeshift workshop had already been formed in Fourth Army, the personnel being borrowed from a variety of sources, as in the case of engine drivers.

There was already in existence No. 1 (The London and Tyne) Electrical and Mechanical Co., R.E. (T.F.) which had been formed from the London Electrical Engineers in December, 1915, to deal with specific requirements in the First and Second Armies in respect of trench warfare, and also subsidiary works such as lighting of hospitals and machinery used for general purposes.

The functions of the Company in respect of electrical and mechanical plant were defined as follows :—

(i.) Instalment.
(ii.) Training of personnel for the running of such plant when installed.
(iii.) Inspection and advice to ensure full value being obtained from any plant available.
(iv.) Preparation of projects for installations.
(v.) Minor repairs.

The permanent detachment of company personnel for the management of plant was not contemplated.

The total R.E. personnel of the Company was only 116 all ranks, who were mainly occupied with such work as electric lighting of hospitals, C.C.S.'s, etc., and it was therefore not possible to obtain material assistance from the Company for Army Water Supply.

When the Somme offensive was decided on, a detachment of this unit was sent to the Third Army to assist them in mechanical work, the bulk of which was subsequently transferred to Fourth Army, as the preparations for the attack progressed.

In November, 1916, a proposal was submitted to the War Office for the formation of five new E. and M. Companies (one for each Army) and for the absorption of the London and Tyne E. and M. Company. This was approved by the War Office in December, 1916, and the formation of the five companies was proceeded with forthwith.

While the advantage of having the Electrical and Mechanical work organized was very considerable, the nett increase of R.E. personnel was small. Out of a total R.E. personnel (all ranks) for the five companies of 1,315, only 543 were additional, the balance 772

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being found by the reduction of other R.E. units. Army Troops Companies were reduced by eight O.R.'s each, Siege Companies by 16 each, and the two Land Drainage Companies by 199.

These E. and M. Companies were Army Companies, and worked under the instructions of the C.E., Army, but in *liaison* with Corps Water Supply officers and the Army Troops Companies. They had numerous other duties connected with electricity, machinery and workshop repairs, etc., and were from the first very much overburdened; but military considerations and shortage of men prevented the provision of sufficient personnel.

11. *Boring for Water.*—Boring plant for use in the chalk area was ordered on a small scale in the spring of 1915. An officer with large boring experience in civil practice was put in charge of the machines, and men were borrowed from Army Troops Companies, infantry, etc., to operate them.

The drills did useful work during the concentration preceding Somme operations and the battle, and a great impetus was given to boring by the success of the airlift pump. Whereas the maximum quantity raised from a 6-inch bore-hole by an ordinary pump had been about 3,000 g.p.h., it was found possible with the airlift to raise from 6,000 to 10,000 g.p.h. in suitably chosen positions. As much as 30,000 g.p.h. was obtained from a bore in the Ancre valley, using two airlifts simultaneously.

The work suffered severely, however, from the unorganized state of the drilling crews, and their liability to sudden withdrawal when units moved.

The formation of three Water Boring Sections, R.E., was therefore taken in hand and approved by G.H.Q. in March, 1917, the sections being attached to the E. and M. Companies of the three Armies. The establishment was designed on the basis of the operation of four drills per section, the normal crew per drill consisting of a corporal and eight artificers. Sections were later formed in the two Northern Armies, making five sections in all, or one per Army.

As the demand for bore-holes increased, the establishment was found to be inadequate, and attached labour was always required. The amended establishment approved in July, 1918, increased each crew to 12, of whom a portion were rated as pioneers. These Boring Sections were under the orders of the C.E., Army.

In addition to the five Army Boring Sections, R.E., the Australian E. and M. Company had one section organized for boring work. Their drills were at the disposal of the Inspector of Mines, and were used in various parts of the area as occasion arose. The bulk of the work of this section was done on L. of C. area for the Director of Works.

12. *Appointment of I.R.E.M. at G.H.Q.*—In June, 1918, an Inspector of R.E. Machinery was appointed, attached to the staff

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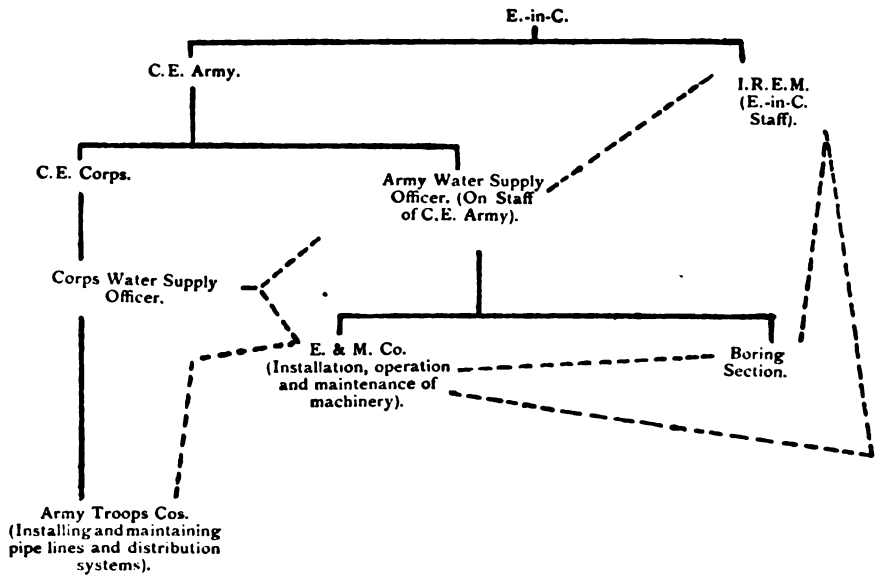
of the Engineer-in-Chief. His duties were to deal under the Deputy E.-in-C. with all technical questions affecting Army E. and M. Companies and Workshop Companies, and to keep in close *liaison* with Armies. He was also required for the allotment of all Water Supply machinery and stores, and for forecasting requirements. In practice the appointment developed into the equivalent of Water Supply officer, G.H.Q., under the E.-in-C., with certain additional duties.

Diagram of Organization. This completes the development of the general organization up to the time of the Armistice.

The following diagram shows the general lines of responsibility for the R.E. work, though it was subject to local variations in different Armies.


E.-in-C.
C.E. Army.
I.R.E.M. (E.-in-C. Staff).
C.E. Corps.
Army Water Supply Officer. (On Staff of C.E. Army).
Corps Water Supply Officer.
E. & M. Co. (Installation, operation and maintenance of machinery).
Boring Section.
Army Troops Cos. (Installing and maintaining pipe lines and distribution systems).

NOTES.

(i). Full lines show chain of direct technical responsibility.

(ii). Dotted lines show *liaisons*.

(iii). Relations between W.S.O. and E. & M. Coy. varied in different Armies; in some cases as shown in diagram, and in others E. & M. Coy. direct under C.E. Army with *liaison* between W.S.O. and E. & M. Coy.

(iv). Boring sections worked in some cases as independent units as shown, and in others as sections attached to the E. & M. Coy.

13. *Geology.*—The geologist appointed in 1915 to E.-in-C.'s office was fully employed in an advisory capacity, and was available to visit Armies to assist the Army Water Supply officers and Boring Sections. His services were of great use, and the appointment was amply justified by the saving in time and labour effected. He also prepared a series of valuable Water Supply maps, showing the resources of the country, running water, water tables in the chalk country, etc., etc.

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The great effect of the geological structure on the question of Water Supply is well illustrated by a study of the British battle fronts in France and Belgium. In this area the meteorological conditions are sufficiently uniform to constitute only a very minor controlling factor.

A glance at the geological sketch map (*Plate* I.) shows that the area falls into two main divisions—recent beds and tertiary sands and clays to the north, and a great inundulating chalk plateau in the south. The geological section from Ostend to the top of the Notre Dame de Lorette ridge, and from thence to Peronne, shows the general arrangement of the strata along the battle fronts (*Plate* II.)

The chief points to be noticed in the geology may be taken in order, starting at the coastal plains of the North Sea at Ostend, Nieuport, etc. The coastal strip of the Polder Plain, with the exception of their seaward margin of sand dunes, lies below or near high tide level. The Polder Plain consists mainly of marine sands with thin clays and peat beds in certain places in the upper part. Beneath the marine beds of the Polder Plain at about a depth of 100 feet on the coast is found a tough blue impervious clay called the Ypresian clay, which is of similar age to the London clay of England. This clay is found close to the surface near Ypres and over most of the plains of Flanders. The range of hills from Cassel, Mt. Noir to Kemmel with their continuation on the Messines—Wytchaete ridge are relics of sands which naturally come above this clay, but have been worn away by the action of weather from all the clay surface except on this isolated range of hills.

The next marked rise to the south is that of the chalk hills of Artois, but the flat ground running from near Calais to St. Omer to Bethune, although mainly covered by recent alluvial deposits, is underlain by the sands and sandy clays which come below the blue Ypresian clay, and form a basal series to the tertiary strata. These sands, which crop out at the surface near Bethune and St. Omer, are found at a depth of 300 feet below sea level near Ypres, and about 520 feet below sea level at Ostend.

Rising up from the plains of Flanders are the chalk hills of Artois and Picardy. The chalk must not be considered as a whole, because the characters vary both vertically and horizontally. Thus under the plains of Flanders the chalk is found to thin over an old submerged crest of slate rocks, and in this locality it is found to be a compact hard marly chalk with few or no fissures, and contains no water. Again, in the Eastern Artois hills and in Picardy, the upper beds of the chalk are porous and fissured, while the middle and lower beds are marly and impervious.

One of the most striking physiographical features of the battle-front is the abrupt rise of the Notre Dame de Lorette and Vimy Ridge. This great fault brings the lower marly chalk to the surface,

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which has a marked effect on the hydrographical conditions over a considerable area.

To the south, the undulating plateau of Picardy to the valley of the Somme is formed of white upper chalk overlying the marls of the middle and lower chalk. The structure, however, is not that of a uniform horizontal series of beds, but is a series of gentle folds as shown on the geological section. The most important of these folds from a hydrographical point of view is that running through Saulty to Bapaume, and corresponds to what some French geologists have called the Axis of Artois.

From the above short description of the geology of the battle-front it will be seen that in the north the formation is essentially clay with fine sands below, and in the south, chalk. It resulted therefore, that methods of Water Supply were entirely different in Flanders to what they were in Picardy, where the chalk formed the whole country.

It is clearly of importance, before deciding on the type of plant which will be necessary in any undertaking, to have a sound knowledge of the geology of the district, and of the behaviour of the underground waters of the area.

A full account of the geological work will be found in the report on Military Geology on the Western Front (" Work in the Field under the Engineer-in-Chief, B.E.F.," Geology).

14. *American Water Supply Organization.*—The Water Supply Organization that was decided on for the A.E.F. was based principally on the experiences of the British Army, and is of interest as illustrating the Engineer requirements as they appeared to outside observers.

One W.S. Regiment of Engineers was allotted to each Army, the regiment consisting of six companies each about 250 strong—one company was allotted to each of five Corps, and the sixth remained at the disposal of the C.E., Army.

The C.E., A.E.F., had a special Water Supply adviser, and each Army and Corps Chief Engineer also had his special Water Supply officer, who was the C.O. of the battalion or company respectively.

Laboratory Service. All testing and inspection work in connection with water was carried out directly under Engineer W.S. Service.

Water Tank Companies. These were very similar to the British Companies, but were Engineer units, and directly under the control of the W.S. service. They were originally administered by the Q.M.G. Department, but were soon transferred to the Engineers.

Electrical and Mechanical Troops. One regiment per Army, of similar strength, and distribution to the Water Supply battalions.

The general chain of responsibility is shown on *Plate* III. This organization was in actual being in the American First Army, and is believed to have worked satisfactorily.

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APPENDIX TO CHAPTER I.

Notes on Water Supply in Belgium and N.E. France.

1. Since the supplies of the inhabitants of the country which would be covered during an advance are for the most part drawn from sources which are obviously liable to contamination, preliminary enquiries have been made regarding the general probability of obtaining potable water by sinking wells, pending investigations by an expert geologist, Lieut. W. B. R. King, whose appointment has been approved by the War Office.

2. Dr. Strahan, Director of the Geological Survey, and Professor Watts, of the School of Mines, have been consulted by Major Brady, R.E., of the D.F.W. Branch, War Office; and they have discussed the matter with Professor Stanier, of the Ghent University. Stated briefly and in general terms, their opinion is, that within an area roughly defined by a circle of 50 miles radius, described with Oost Ecloo (10 miles N. of Ghent) as a centre, there is no reasonable probability of finding, by any deep-well borings, any water which would be better than that which is obtainable on or near the surface.

3. In Flanders, as far east as a short distance beyond Brussels, and as far as the ridge geologically dividing France from Belgium, the chalk is not water bearing, but is interspersed with clay. Below the chalk the water obtained is unfit for drinking, and is generally impregnated with minerals. N.E. of Antwerp the Bruxellian sands occur, but they yield a ferruginous liquid which is quite unpotable.

4. These statements are confirmed by information given by M. Van der Scheuren, of the Belgian Ponts et Chaussées attached to the Belgian Mission, who has special knowledge of the conditions at Ostend and Bruges, and holds the opinion that for the supply of large numbers of troops in Flanders it would be impossible to rely upon obtaining water from deep wells. There have been many failures in this area to obtain water by deep borings, and in some instances the water so obtained has been no better than that drawn from shallow wells.

5. It will be seen that at both the towns mentioned the public supplies are derived from shallow wells and from distribution systems originating in canals. Such tube wells of artesian character as exist at Bruges are used either for Government or commercial purposes, draw their supplies from comparative shallow strata, and the water is probably not beyond suspicion, though it may be preferable to that obtained from surface wells.

6. M. Chartiez, a contractor of La Bassée, makes a speciality of well boring and is the contractor for the new wells near that town, from which it was proposed to augment the existing supply of Lille. He has an extended knowledge of the locality, and considers that in Flanders shallow wells afford the only possible source of supply, other than canal water.

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7. General Cavelier, Professor of Geology at the Belgian Military Academy, has stated that he was at an absolute loss for the present how to find drinkable water in the N. of Belgium ; and that, in his opinion, the existing local resources would be the only ones available, and that the water would have to be treated chemically and by boiling.

8. The absence of any distribution schemes, based on supplies from deep wells in Belgian towns in the area in question, also points to the fact that they cannot be regarded as efficient sources of supply.

9. In the circumstances it would seem assured that in the area indicated in para. 3 above, the troops can only be supplied with surface water either from canals, ponds, streams, shallow wells, and, in a very few cases, from springs, and that such water will almost invariably be contaminated. The only source that can apparently be depended upon to provide large quantities in summer are the rivers and canals. It will, therefore, be necessary to make provision for treating canal water, preferably on water-tank barges ; and also for the transport of water in barges from places where the water is good to others where it is indifferent ; and possibly to utilize motor transport for the carriage of water from canals to the troops who are some distance from them.

10. It is otherwise in the area S. of a line running roughly through Boulogne, Aire, and Valenciennes. The water-bearing chalk may generally be found at depths varying from 30 metres (100 feet) to 60 metres (200 feet) in the vicinity of La Bassée, Cuinchy, Béthune and at about 70 metres in the district S. of Lille. Near the Lys water is found at greater depths, at Sailly (130 metres), and Bailleul (200 metres). There are a number of artesian wells in this area, and arrangements will be made to get out suitable boring plant. It may, however, be difficult to effect the borings with the speed which is necessary for military requirements; this question is now being investigated.

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CHAPTER II.

STORES AND MACHINERY.

15. *General.*—A great variety of stores was required for Army Water Supply work.

The main sources of supply were :—

(*a*) *Piping and Specials.* Obtained through the Director of Works, and allotted to Armies by E.-in-C.

(*b*) *Tarpaulins, pipe tools and other vocabulary stores.* Drawn from Ordnance mainly by indent of officers in charge Advanced R.E. Parks.

(*c*) *Machinery.* Purchased by War Office on order of Engineer in-Chief, and allotted to Armies by him.

(*d*) *Special Stores.* By local purchase in France when not available from Army sources.

The Chief Engineer, B.E.F. (later Engineer-in-Chief), was responsible for forecasting requirements of Armies, and settling patterns of supplies, and at first demanded them direct from the War Office. The requirements in respect of Ordnance stores, tarpaulins, etc., were also forecasted by the Engineer-in-Chief, and distributed on his advice to Armies and L. of C.

In July, 1918, the provision of stores in (*a*), (*c*) and (*d*) passed to the newly formed Directorate of Engineering Stores.

By this time, supply systems were more or less stabilized and regular, so that the D.E.S. could arrange for supply on records of average requirements, consulting the Engineer-in-Chief regarding his orders.

16. *Piping.*—In the early stages of the War, the standard sizes of pipes stocked in R.E. Parks were 2-inch, 1½-inch and 1-inch diameter.

When power pumping with mains of some miles in length was provided for, the necessity of larger pipe was foreseen, and after careful consideration pipe of 4-inch internal diameter was adopted.

In certain special cases 6-inch diameter mains were used, but this formed only a small percentage of the whole. The 4-inch pipe was sufficient to meet almost every case, and this size proved thoroughly satisfactory for Army work.

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The first 4-inch steel pipe used was flanged pipe brought from mobilization stock in England. Trouble was experienced in quick laying owing to there being several types of flange, and more than one size of bolt. It was also found that when laid, the flanges were frequently broken by vehicles driving over the pipe lines, and breaking off flanges.

Steel pipe with screwed joints was finally adopted and used entirely. This was found much more satisfactory, though it requires more skilled men to lay it. Pipes laid by unskilled men gave frequent trouble through crossed threads, insufficient screwing, and other causes.

A real *quick-joint* steel pipe is still to be sought—some form of armoured rubber joints with clips has been suggested as a possible solution.

Of the other sizes of pipes the 6-inch pipe used was also screw-joint steel pipe. 2-inch and 1-inch pipe were used in large quantities for distribution schemes, but little use was made of 1½-inch, and orders of this size were finally stopped. It was the intention to use up the stocks already in France, and thereafter to discontinue its use entirely. Supplies of 4-inch, 2-inch, 1½-inch and 1-inch pipes were well maintained, and no serious shortage occurred at any time. All pipes were supplied with a socket on one end. The 4-inch pipe had in addition a ring on the other end to protect the thread.

17. *Fittings.*—In 1916 great difficulties were experienced in getting enough fittings of all sorts, but large orders were placed in England and America, and the supply gradually improved.

The proportion of fittings which should be ordered per mile of piping was difficult to determine. Army Water Supply officers were asked to submit scales of fittings from their experiences on the ground. The estimates, however, differed so widely as to be of comparatively little use.

The following table gives the average number of fittings per mile of pipe actually issued from No. 3 R.E. Park over a period of 24 months. This should form a fair basis for estimating, as the Park figures cover not only the actual numbers used in the work, but also wastage, a considerable item under war conditions.

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Number of Specials Expended per Mile of Piping Calculated on Actual Expenditure from 1. 6. 15. *to* 7. 2. 18 *as recorded at No.* 3 *R.E. Park.*

	4-inch.	2-inch.	1½-inch.	1-inch.
Bends Socketed	5·7	32·0	40·5	86·5
Backnuts	5·2	62·5	31·8	169·0
Elbows	1·5	46·6	45·3	123·0
Springs assorted	3·0	10·5	18·3	30·0
Caps	0·28	7·9	12·5	25·5
"T" Pieces equal	0·92	5·0	32·8	82·1
,, ,, reducing 4" to 2"	2·2	—	—	—
,, ,, ,, 4" to 1½"	0·15	—	—	—
,, ,, ,, 4" to 1"	0·12		—	—
,, ,, ,, 2" to 1½"	—	8·7	—	—
,, ,, ,, 2" to 1"	—	19·6	—	—
,, ,, ,, 1½" to 1"	—	—	5·7	—
,, ,, ,, 1" to ¾"	—	—	—	8·4
Plugs	1·58	12·4	15.4	41·0
Sockets	3·35	37·0	42·5	220·0
Nipples	1·89	23·5	30·0	85·0
Flanges, Screwed	1·85	16·8	12·7	11·4
Cocks, Stop	—	23·5	24·0	43·5
,, Bib	—	1·6	10·1	83·0
,, ,, ¾"	—	—	—	—
Valves, Stop or Sluice	3·05	—	—	—
,, Reflux	0·21	0·22	—	—
,, Air	0·08	—	—	—
,, Ball	—	0·16	1·0	0·07
Sockets, reducing 4" to 2" ...	1·78	—	—	—
,, ,, 4" to 1½" ...	0·19	—	—	—
,, ,, 4" to 1" ...	0·29	—	—	—
,, ,, 2" to 1½" ...	—	7·1	—	—
,, ,, 2" to 1" ...	—	17·6	—	—
,, ,, 1½" to 1" ...	—	—	42·3	—
,, ,, 1" to ¾"				67·0
Junction 4-way	0·08	4·7	10·2	7·0
Connecting pieces, long) ...	10·8	21·0	6·6	38·2
,, ,, short)				
½-Junction (4")				
¼-Junction (4")				

This list of fittings was found sufficiently comprehensive to meet ordinary conditions, and represents the standard items of supply. The half-junction pipes (4-inch) and quarter-junction pipes (4-inch) listed, were half and quarter lengths of 4-inch pipe, with long connector thread and backnut at each end, and were intended for quickly making good breakages in mains, but were finally dropped as being unnecessary.

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Special Fittings, etc. From time to time fittings other than those on the standard list were required. These were partly made locally by Army Troops Companies, Army Workshops Companies, etc., and partly demanded from the Base workshops. This led to a great variety of patterns being used. At a meeting between the I.R.E.M. and the Army Water Supply officers in August, 1918, a beginning was made with the standardization of necessary special fittings, and elimination of others which were considered extravagant.

Fittings for Quick Repair. A number of types of clips, cover plates, and sleeves were used from time to time for covering shrapnel holes and other small damages to 4-inch pipe lines. A standard cast iron sleeve was adopted, which is shown in *Plate* IV. This could be used also for completing more extensive repairs or replacements, without the necessity for special screwing of pipes. A further use was in making connections up to 2-inch to an existing main, the sleeve being bored and tapped to take the connection required. Lead wool should be supplied for jointing, as in many situations the use of a fire for melting lead is inadmissible.

Water Bottle Fillers. Some means had to be provided for rapidly filling men's water bottles. A length of 4-inch pipe drilled at intervals, and with wooden beer taps driven into the holes was used at first, but the beer taps were not satisfactory, and bibcocks screwed into the 4-inch pipe were adopted as standard. This is shown on *Plate* V. Two sizes were made, one about 12 ft. 6 in. long, and the other about half that length. Galvanized iron tanks with bibcocks connected directly to them were also used.

Branch Pipes. 45° branch pipes for 4-inch pipe were found to be much needed, and were added to the list of standard fittings for 4-inch pipe only.

Pipe Line Notice Boards. It was found difficult to mark pipe lines, tees, etc. effectively. If wooden pickets were used, they were taken as fireiwood, and screw pickets were frequently removed. A cheap and smple type which is not easily removed is shown on *Plate* VI.

4-inch Flexible Pipe. Much time was lost in cutting, bending, and fitting 4-inch pipe for connections to pumps, often in circumstances when every hour was of value. It was decided to provide 4-inch flexible pipe with screwed connections in six feet, eight feet, or ten feet lengths, for these connections.

Tanks. The standard sizes of metal tanks supplied were :—

1,600 gallon, approximately 8 feet square by 4 feet deep, built up of 4 feet by 4 feet pressed steel flanged plates. These were bolted together, and joints were made with strip lead. Skilled labour is required to erect and caulk them, but when properly erected they were most satisfactory. While 1,600 gallon was the combination most commonly used, the plates can be built up to other sizes, provided suitable internal tie rods

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are used. They can be made two plates (*i.e.* 8 feet) deep, and of various widths and lengths. Combinations up to 9,600 gallons were used.

400, 200, 100, and 50 gallon galvanized iron tanks, both rectangular and of circular corrugated type, were supplied in these sizes and were used in large quantities. The 100 and 50-gallon sizes were in great demand for trench work and battery positions.

During 1918 the demand for small tanks was enormous, and to make up for deficiencies, an improvised tank was made in Army workshops, and used in a few stationary points.

A common type is shown on *Plate* VII. These were not very satisfactory, but answered the purpose for a time.

18. *Machinery—General.*—Up to the time of the formation of the Directorate of Engineering Stores under the Q.M.G. in July, 1918, all Water Supply machinery was purchased by the War Office on the orders, and to the general specifications of, the Engineer-in-Chief. By arrangement with the Director of Works, a large proportion of the pumps and engines required for L. of C. were purchased by the same means.

After the formation of E. and M. Companies, machines were allotted by the E.-in-C. to E. and M. Companies on the indent of Chief Engineers, Armies, all stocks of pumping machinery in Armies being kept by these companies at the disposal of Chief Engineers, Armies. The companies had large discretionary powers as to replacing machines which needed repair, but only sent them out for new installations on instructions from Army.

Local Purchase and Hire of Machinery. In 1915 and 1916, engine pumps were, when necessary, purchased or hired locally by C.R.E. of Divisions, but this practice led to difficulties, and was finally stopped. Owing to frequent moves of Divisions, it was a very difficult matter to keep proper records of agreements.

Finally, it was found necessary to make all machinery "Area property," *i.e.*, it was not allowed to be moved, except on the authority of the C.E., Army. This was done to prevent the lighter class of machines being dismantled and taken away by formations when moving, in which way great inconvenience to incoming troops was caused.

Issues of Machinery. The following table gives in general figures the number of power-driven pumps and engines issued to Armies from the Base depôts from March 1st, 1917, onwards, before which date complete records of issues are not available.

The table is divided into three periods as follows :—

The period from 1. 3. 17 to 1. 10. 17, during which several major operations took place.

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From 1. 10. 17 to 21. 3. 18, a period of comparative quiet, with the exception of the short battle of Cambrai.

From 21. 3. 18 to 11. 11. 18, *i.e.*, from the date of the first German offensive of 1918, to the date of the Armistice, a period of almost continuous operations.

Type of Pump.	Issues 1. 3. 17 to 11. 10. 17.	Issues 1. 10. 17 to 21. 3. 18.	Issues 21. 3. 18 to 11. 11. 18.	Total.
Ram pumps and oil or petrol engines	8	5	78	91
Steam pumps	31	8	96	135
Tube well pumps and oil engines	33	32	65	130
Trench pumps	172	54	164	390
Centrifugal pumps	40	6	75	121
Airlift Sets	22	14	35	71
Water Lifts	28	12	63	103
Total	334	131	576	1041
Average issue per month	48 sets.	23 sets.	75 sets.	51 sets.

The above figures clearly indicate the demands for Water Supply machinery caused by active operations, as against " peace warfare."

Variety of Types. The number of varieties of pumps and engines was very large in the earlier months of 1916, and many unsuitable types were received. This was due in part to the lack of experience, to the impossibility of getting suitable pumps manufactured in time, and in part to the fact that the number of groups required had been largely under-estimated. All available stock had to be purchased. In consequence, any pumps likely to be of any use, were bought from makers' stocks and elsewhere.

19. *Standardization of Types.*—In order to consolidate demands and limit the number of types of pump and engine as far as possible, a meeting was held in November, 1916, after the Battle of the Somme, in the E.-in-C.'s office under the Chairmanship of the Deputy E.-in-C., at which the Chief Mechanical Engineer and the Army Water Supply officers were present. At this meeting the probable requirements were fully discussed, with the result that large orders were placed for a limited number of types of pump and engine. With a very few additions, these types were adhered to until the armistice.

While, as noted above, the types were standardized, *i.e.*, the pump duties required, type of engine (whether oil, petrol, or steam), type of pump (whether ram, centrifugal, etc.), it was found impracticable to standardize makes of machine. The importance of this was represented on many occasions to the C.M.E. at the War Office, but he was faced with serious difficulties.

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Firstly, owing to congestion of work and shortage of raw material, the contractors quoted long deliveries, and frequently even these were not worked up to. As a result, in order to get the whole of an order from France delivered within a reasonable time, it frequently had to be split between a number of makers. For instance, an order for 100 ram pumping sets of a particular duty might have been distributed between three or four pump manufacturers, and possibly as many engine manufacturers.

Secondly, it was often impossible to place repeat orders for the reason that the whole of a particular manufacturer's output had been in the meantime contracted for by another buying department or service, such as the Director of Transport, the Admiralty, etc. The inevitable result was a continuous increase in the number of makes of machine.

To get over this difficulty, the system was adopted of placing running contracts with selected manufacturers for the delivery of a certain number of machines per month, with power to determine the contract on giving a fixed amount of notice. This system was only started in August, 1918, by the D.E.S., and consequently was not subjected to practical test, since deliveries on running contracts were only beginning to mature when the armistice was signed. There is, however, every reason to think that it would have done much to secure the ends in view.

In order to arrive at a basis for letting the contracts, estimates were prepared in the E.-in-C.'s office of requirements for the following six months. These estimates were partially based on previous consumption, but were of necessity largely guess-work, as demands vary so largely according to conditions of warfare, type of country, etc.

In the following notes on various machinery in common use, only the later types, as evolved by experience, are mentioned, and not the earlier heterogeneous collection.

20. *Ram Pumps.*—Ram pumps were used of the following duties :—

(*a*) 6,000 g.p.h. × 350 feet head.
(*b*) 2,500 ,, × 350 ,,
(*c*) 2,000 ,, × 60 ,,
(*d*) 1,000 ,, × 120 ,,

(*a*) 6,000 *g.p.h.* × 350 *feet head.* These are vertical treble ram pumps of ordinary type, and present no special features. They are belt-driven by 14 h.p. oil engines.

They are only suitable for work of a semi-permanent type, and were not extensively used in the Army area. They are not recommended for adoption as a standard, as centrifugal pumps are lighter and more suitable for this duty.

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(*b*) 2,500 *g.p.h.* × 350 *feet head.* There are two distinct types of pump, and also of engine, for this duty in use, viz. :—

(i.) Vertical treble-ram pumps of various makes (Tangye, Pearn, Evans, Matthews, Brackett), but driven by 7 h.p. oil engines, also of various makes (Lister, Tangye, Blackstone, Shanks, Petters). (See *Photos* I and II).

(ii.) Horizontal 2-barrel double acting piston pumps (Hayward, Tyler and Co.), but driven by similar engines to (i). *Photo* III.

Both of the above combinations proved eminently satisfactory where of sufficient duty, and large numbers were in use.. They were mounted on channel or timber frames so as to save time in erection. Twenty-four sets were issued from 1st March, 1917 onwards, but many more than this number were issued previous to this date, and were in use for long periods. The most popular were probably the Tangye and the Hayward Tyler, on account of their comparative lightness and ease of erection.

As water requirements increased, demands for these sets decreased in favour of higher duty plants.

(iii.) The same pump as (ii.), but sent out mounted up complete on a light channel frame with a 2-cylinder petrol engine, cooling tank, etc. The pump was belt-driven. This formed a compact combination well adapted for use in dug-outs and confined spaces, the floor spaces occupied being only about 10 ft. 6 in. × 3 ft. 0 in. They were, however, not very popular, owing to unreliability of the engine.

Thirty-one sets were issued from 1. 3. 17 onwards.

(*c*) 2,000 *g.p.h.* × 60 *feet head.*

(*d*) 1,000 *g.p.h.* × 120 *feet head.*

These were two types of the same make, and were obtained from the French " Service des Eaux," with whom they were a standard type of pump. (See *Photo* IV.). They were made by a French firm, Guy & Mital, and consisted of a single-ram pump driven by a petrol engine (usually 1½ h.p. Japy) by a short belt with jockey pulley. The only essential difference was in the size of the ram. They were mounted up after the style of a wheelbarrow, but with two wheels in front. They can be easily moved by one man. They gave very good service, and were in demand by all Armies. A number of them were taken over in position from the French at various places on change of areas, and thirty-two were issued. Had they been available, it is probable that the issues would have amounted to several hundred.

Enquiries were being made by the C.M.E. as to the provision of a similar set from England, when the armistice stopped the proceedings.

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21. *Steam Pumps.*—The following are the chief types of steam pump used :—

(*a*) Steam duplex, duty 5,000 g.p.h. ×500 feet head.
(*b*) Steam duplex, duty 4,000 ,, ×350 ,,
(*c*) Sinking Pumps.
(*d*) Merryweather Fire Pumps.
(*e*) L.C.C. Fire Engines.

(*a*) *Steam duplex* 5,000 *g.p.h.* ×500 *feet head.* These were Tangye pumps, with Cochran, Robey, or Ransome boilers. They proved to be too big and cumbersome for Army use, and were not used to any extent.

(*b*) *Steam duplex* 4,000 *g.p.h.* ×350 *feet head.* Various makes of pump were supplied of this duty including Worthington, Hayward Tyler, and Tangye pumps. The boilers were of the vertical water tube or cross tube type, with an evaporative capacity of about 600 lbs. per hour. They were made by Cochran, Spencer, Farrar, Lumby, Balmforth, etc. These sets proved thoroughly reliable, and were largely used outside the shelled area. They were unsuitable for forward areas, as the smoke and steam were apt to draw fire. Twenty were issued after 1st March, 1917, and a number before that date.

(*c*) *Sinking Pumps.* A small number of Cameron sinking pumps were supplied for wells. They were not as a whole satisfactory, and supply was stopped.

(*d*) *Merryweather Fire Pumps.* These are portable sets with detachable 2-wheeled hand carriages. They are designed for fire fighting purposes, and have a quick steaming water-tube boiler on which steam could be raised in a few minutes. Two sizes were used.

The " No. 1 Valiant " pump (see *Photo* V) had a specified duty of 5,000 g.p.h. ×35 feet head, and this is an Ordnance supply. It is described in Section 29 E. of the vocabulary of stores as " Pump, portable, 5,000 g.p.h. vertical, Merryweather's Small Valiant, and should be indented for as such and not under the designation " No. 1." Confusion has several times arisen over this point. This pump, though specified for 35 feet head, can in practice be used up to 60 feet head.

The No. 2 " Valiant " pump (see *Photo* VI.) was of similar design, but larger, with a specified duty of 7,200 g.p.h. ×250 feet head. It was supplied with two different-sized water cylinders of $5\frac{1}{4}$ inches, and $3\frac{3}{4}$ inches diameter. With the former it had not enough power to deliver at a greater head than about 150 feet, but with the latter, and a delivery reduced to about 5,000 g.p.h., 250 feet head could be attained.

These fire pumps proved of the greatest use, being very portable, and were largely used where quick installation was essential. A drawback was the difficulty of providing fuel during moving warfare.

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(*e*) *L.C.C. Fire Engines.* A number of London County Council steam fire engines, which had been superseded in 1916 in the fire brigade by more up-to-date engines, were bought, since other types could not be obtained, and it was hoped that they might be found suitable for large deliveries, especially for horse watering. While they proved of great use in emergencies in the Somme and other operations, they required highly-skilled drivers to handle them effectively, and to maintain them in running order. As more up-to-date plant became available, they were superseded, and fell into disuse for army water supply. Many of them were afterwards used as fire engines at base depôts.

22. *Tube Well Pumps.*—Three types of tube well pumps were mainly used :—

(*a*) With duty of 1,000 g.p.h. × 250 feet head.
(*b*) With duty of 3,000 ,, × 200 ,,
(*c*) With duty of 3,000 ,, × 150 ,,

There were also some odd pumps of 1,500 g.p.h. and 2,000 g.p.h. used, but these were few in number, and were not standard pumps.

(*a*) *With duty of* 1,000 *g.p.h.* × 250 *feet head.* (See *Photo* VII.) These were the most commonly used type. They had " A " frame well heads, and the barrels were designed to enter a 6-inch bore-hole, the internal diameters being about $3\frac{3}{4}$ inches. They had internal rods, and a 4-inch rising main for which ordinary 4-inch water pipe could be used. They were extensively used both on bore-holes and ordinary wells. They were belt-driven by 7 h.p. oil engines precisely similar to those used for the 2,500 g.p.h. ram pumps (see para. 20 (*b*)).

Duke & Ockenden, Isler, Potter, and Warner pumps formed the bulk of those supplied. This type of pump proved suitable for the work, though there were some mechanical troubles, some of which are inherent to borehole pumps. They could be mounted complete with engine on channel or timber frames. One hundred and eleven sets were issued subsequent to 1st March, 1917, the D. & O. type being perhaps the most popular in Armies.

(*b*) *With duty of* 3,000 *g.p.h.* × 200 *feet head.* Twenty-four pumps of this duty were designed and built in the Second Army R.E. Workshops at Hazebrouck. They were specially designed, with a 3-feet stroke, and small diameter barrel in order to enter a 6-inch diameter bore-hole. Although not altogether successful, and seldom able to obtain a duty of more than 2,000—2,400 g.p.h., they were none the less a very creditable example of field workshop production, and met a decided want for a time. They were belt-driven, partly by Gardner oil engines, and partly by any engines which happened to be available.

(*c*) *With duty of* 3,000 *g.p.h.* × 150 *feet head.* An order for 24 pumps of this duty was placed for the Palestine front, but they were

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diverted to France. The minimum diameter of bore-hole on which they could be used was eight inches, but they proved popular for wells, and repeat orders were placed. They were Duke & Ockenden pumps, belt-driven by 10 h.p. Tangye oil engines.

According to one very experienced W.S. officer the head works of all types were capable of improvement, and appeared heavy and clumsy in comparison with the best German types.

Deep-Well Hand-Pumps. Towards the end of 1917 many demands were made by Divisional units for some form of deep-well hand-pump, to replace the usual windlass and bucket. The only existing type was supplied by Ordnance under the description " Pumps, Deep Well—100 ft.—for hand only." This was found to be quite unsuitable; the mechanical advantage was low, the frame too weak, the pipes, rod and connections unsatisfactory for various reasons. Various alterations to this pump met with no success.

There was the greatest difficulty at this time in getting new patterns manufactured in England, but in 1918 an order was finally placed for a number of hand pumps capable of delivering 300 gallons per hour at 100 ft. head, and suitable for use on a 6-inch bore-hole. None of these had been received before the armistice, but there certainly appears to be a future for a standardized pump of this description. A number of similar pumps left behind by the Germans in their retreat were fitted up, and proved quite successful.

(*Note.* In the Second Army Area " flap valve " plungers were found unsuitable, owing to the difficulty of keeping out the fine sand, and ball valves were substituted, which gave much better results).

Well Windlasses. A standard pattern hand windlass was made at Base Workshops in considerable numbers. This is shown on *Plate* VIII.

23. *Centrifugal Pumps.*—These formed a very important class of pump, particularly for the larger units, on account of their portability and compactness.

The chief classes were :—

(*a*) Multi-stage pump, duty 7,200 g.p.h. × 500 feet head.
(*b*) ,, ,, ,, 5,000 ,, × 500 ,,
(*c*) ,, ,, ,, 6,000 ,, × 200/250 feet head.

In addition to the above, the following were used, and are worthy of note :—

A few 12,000 g.p.h. × 600 feet head pumps, belt-driven by 60 h.p. engines. These were only required in special cases.

One or two 12,000 g.p.h. × 600 feet head pumps, direct connected to petrol engines.

For pumps of these deliveries it is most essential to use petrol centrifugal sets in army areas, on account of weight and bulk.

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As an instance, a direct connected petrol centrigufal set, rated to give 12,000 g.p.h. × 600 feet head, weighed 2¾ tons complete, and could be transported in one 3-ton lorry, whereas a treble-ram pump of the same duty, driven by a 70 h.p. semi-Diesel engine, weighed—engine and pump together—22 tons. The heaviest part weighed five tons, and required a special lorry.

One 33,000 g.p.h. × 150 feet head pump, belt-driven by a 60 h.p. petrol engine, was installed in a dug-out in Arras as a stand-by to the town supply.

As regards the types noted above as in more general use :—

(*a*) *Multi-stage pump, duty* 7,200 *g.p.h.* × 500 *feet head.* (See *Photo* VIII.). This was a 7-stage pump, geared to a 4-cylinder petrol engine. The engine was radiator cooled. The set was similar to those in use on the modern motor fire engine, and was mounted up complete on a channel frame. It could be transported on a 3-ton lorry, and could be set on a timber foundation. The combinations used were Dennis engines with Mather & Platt pumps, and Dorman engines with the same pumps. *Photo* VIII. shows the latter set, and *Photo* IX. shows one of the former sets being installed at Ypres. This set was destroyed later by a direct hit from a large-calibre shell. These sets did excellent work, and were used on a number of the larger water systems. Fifty-six were issued after 1. 3. 17.

(*b*) *Multi-stage pump, duty* 5,000 *g.p.h.* × 500 *feet head.* Direct coupled sets, radiator cooled. Eighteen of these were ordered and did good work, but repeat orders were not placed, as it was decided to be unnecessary in addition to the 7,200 g.p.h. size.

(*c*) *Multi-stage pump, duty* 6,000 *g.p.h.* × 200/250 *feet head.* (See *Photo* X.). Direct coupled sets, radiator cooled. The combinations used were Gwynne pumps with Aster petrol engines, and the same pumps with Keighley petrol engines. A small number of Berger pumps mounted on a frame with a short belt-drive from Aster petrol engines. The direct coupled sets were adopted as a standard type, and gave good results. Thirty-one sets were issued after 1. 3. 17, and a number before that date.

Trench Pumps. These were centrifugal pumps, direct connected to small petrol engines of motor-bicycle type. They were designed for pumping out trenches, and mine galleries, in the days of mine warfare, and derived their name from this fact. For many reasons they were found unsuitable for this purpose, and were diverted to Water Supply. They were of many makes, among which may be mentioned Pelapone, Wilton, Day, Oswald Stott, Flexala, Pulsometer, etc. The duties varied somewhat, but were about 2,000 to 2,500 g.p.h. against about 20-30 feet head.

The best of them was probably the Pelapone, but they all gave much trouble, even with skilled men, and were quite useless in the hands of

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semi-skilled or unskilled drivers. They were issued in large numbers, 390 being issued after 1. 3. 17, but many of them found their way to the scrap heap. Pelapone pumps were fitted on the vehicles of the Water Tank (M.T.) Company for filling tanks, and were generally successful.

24. *Roto-plunge Pumps.*—These are rotary pumps with plungers worked off a central shaft. They are direct coupled to petrol engines, and form a light compact set. A few pumps of duty 6,000 g.p.h. × 50 feet head were used, but the type adopted as standard had a duty of 3,000 g.p.h. × 115 feet head (see *Photo* XI.). Twenty-four of these were issued after 1. 3. 17, and many more would have been in use had they been available.

For convenience, the pumps are included with the petrol centrifugal sets in the table in para. 18.

25. *Airlift Sets.*—Airlifts proved to be an invaluable means of raising water from bore-holes in the chalk country. Whereas 3,000 g.p.h. was the maximum raised from 6-inch and 8-inch diameter bore-holes with a tube well pump, as much as 10,000 g.p.h. was often obtained from a 6-inch bore-hole with an airlift. Owing to the difficulty in obtaining deliveries, a great variety of makes were ordered.

Compressors with duties varying from 100 cubic feet to 145 cubic feet of free air per minute were supplied by :—

Ingersoll Rand (exceptionally good for stationary work—but not very portable).
Broome & Wade,
Lacy Hulbert (generally used on lorries),

driven in various combinations by different makes of petrol engines, *e.g.*, De Dion, Pelapone, Keighley, Thorneycroft, Dorman, Dixon Bros. & Hutchinson, Aster, Coventry Simplex.

For semi-permanent installations, a very useful combination was an Ingersoll Rand horizontal single-cylinder compressor 145 cubic feet capacity, driven by a 24 h.p. Hornsby oil engine.

Other sizes supplied were :—Beattall compressors, 80 cubic feet per minute, with 14 h.p. Hornsby oil engine ; Broome & Wade compressor 60 cubic feet per minute, direct coupled to Coventry Simplex engine ; Ingersoll Rand compressor, 21 cubic feet per minute, with 5 h.p. Petter Junior engine.

None of these three types were extensively used, but some of the small 21 cubic feet compressors were on order for use in bore-holes in the very fine Thanet sands, where a yield of about 1,000 g.p.h. was the maximum obtained from a 6-inch bore-hole.

The arrangement of piping in the bore-hole was dependent on the size of the compressor, but in the chalk country in 6-inch bore-holes, a 4-inch rising main was used with a 1-inch diameter internal air

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pipe. The air pipe was frequently perforated over a length of about two feet with a series of ⅛-inch diameter holes in order to break up the air into small bubbles as it entered the water. About eight to ten feet of plain air pipe was left below the perforations, and the bottom of the pipe left open. A drawing of a standard airlift head is shown on *Plate* IX.

A great advantage of the airlift is that there are no working parts below ground level, and consequently the valve and plunger troubles so common on tube well pumps, are eliminated. The usual ratio of lift to immersion was from 1½ : 1 to 2 : 1. All compressors were designed for a working pressure of 100 lbs. per square inch.

26. *Mobile Air Compressor Plants.*—In order to save small installations and engine drivers, and to meet unforeseen contingencies, such as a sudden movement from one area to another of a large body of horses, the system of mounting compressor plants on 3 or 5-ton lorry chassis was adopted in the Southern armies. Storage tanks or reservoirs were provided at the bore-holes, and the air pipe and rising main installed. A compressor lorry visited the bore-hole, was connected up to the 1-inch air pipe and worked as long as required to fill the reservoirs, when it was moved on to another bore-hole. In this way the advantages of a large capacity pumping station were obtained without the necessity for any fixed plant, and one compressor plant could supply water at several water points during the day.

After the retreat of March, 1918, a number of bore-holes were put down in various parts of the Southern Army areas, ready for use in the event of further German attacks on that front. They also proved of great value in the advance in August and September, 1918, over the ground previously held by the British, since the Germans had left a number of the old British bore-holes intact, and compressor lorries could be sent up, and the airlifts put into operation.

During the advance on Bapaume in August, 1918, nearly 5,000,000 gallons were raised in one week by compressor lorries in the Third Army.

For photographs of "Compressor Lorries" see *Photos* XII. and XIII.

Plates X. and XI. show details of mountings for two combinations.

27. *Water Lifts.*—Under this heading are included "Chaine Helice" pumps and "Belt pumps."

"*Chaine Helice*" *Pumps.* These were of French make, and consisted of a special chain running over a pulley at the top, and round a counter-weight pulley at the bottom. The counter-weight pulley was immersed a metre or more in the water. The "Chaine" consisted essentially of two parts, viz. :—a light internal chain to take the strain, and round it a spiral of steel wire attached to the chain at intervals.

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Lengths of chain were joined up to make any desired length by split links and swivels.

When the chain was drawn rapidly through the water, it lifted water with it to the surface. The water was thrown off by centrifugal force as the chain passed the top pulley, and was caught in a collecting box surrounding the pulley. The power pumps were drawn by Japy engines (French make), and gave fair satisfaction up to depths of about 100 feet. There were, however, many troubles with broken chains and lost counter weights, and it was found advisable to equip the pumping station with a grappling iron and length of cord, with which to recover the chain from the well. The delivery was about 600 to 700 gallons per hour.

Belt Pump. This consisted of a canvas or jute belt eight inches wide, running on a pulley about 12 inches to 15 inches diameter, and dipping into the water in the well. No counter weight of any kind is required. The water is brought up on the belt, and thrown off into a collecting box by centrifugal force on reaching the top pulley. The type was developed from a belt pump found installed at a French Chateau.

The most commonly used type had a frame designed to fit into a G.S. wagon, with the belt pulley cantilevered out beyond the back of the wagon. A drawing of this type built of light steel sections, is shown on *Plate* XII. The pump was driven by a 5 h.p. Petter Junior 2-stroke engine mounted on the frame. This type proved of the greatest value in emergencies, and is well worth further development. It must be considered in the experimental stage at present, as the proper belt speeds, immersion, etc., for different depths of well have not been fully established.

The results of some experiments carried out are given in the Charts on *Plate* XIII., but these are not entirely conclusive, as they do not tally with cases which have occurred elsewhere.

The best type of belting, both as regards life and water carrying power, also needs further experiment.

Belt pumps were used on wells up to 200 feet in depth. Fifty-two were issued after 1. 3. 17, and a number were built locally in Army workshops.

28. *Spare Engines and Parts.*—It was found from experience that breakdown was far more frequent in the engine than in the pump, and consequently it was desirable to carry a larger stock of engines than pumps. Further, whereas the pumps rarely required general overhaul, this was necessary for the engine. As it was not possible in the absence of stand-by plant to stop a station to enable this to be carried out, the policy was largely adopted of changing the engine bodily, and bringing the damaged or worn one into the E. and M. Company shops for repair.

Between 1. 3. 17, and the date of the Armistice, 80 spare engines

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from 7 to 10 h.p., and 89 engines of about 5 h.p. were issued. Part of these were used to drive belt pumps locally built in Armies, existing pumps in French factories, etc., but the greater number were used as noted above.

Engine Power. It may appear that some of the pumping sets were over-engined, as for instance, the 1,000 g.p.h. tube well pumps with a 7 h.p. engine. It was found, however, most desirable, owing to the conditions under which the plants were operated, to allow a broad margin in estimating power required.

Firstly, the fuel was of very poor quality, and not equal to that on which the rating of the engine is based.

Secondly, the engine drivers were frequently only semi-skilled men and incapable of getting the best results.

Thirdly, the running hours were apt to be very long. From 18 to 22 hours a day running time over periods of weeks were not infrequent and even longer hours were by no means unknown ; a run of six days in Third Army Area is on record. With an engine running at the limit of its power, these conditions mean frequent breakdown and stoppage, often at a most critical moment.

For the above reasons some of the sets, particularly in the case of petrol engines, were found to be under-powered for active-service conditions.

Spare Parts. In 1916 very great difficulty and delay were experienced in obtaining spare parts for machines of all kinds, which had been hurriedly purchased to meet the emergency of the Somme battle.

An Army Troops Company or other unit in charge of a machine, would indent for spare parts for the particular machine through Chief Engineers, etc. It was frequently three or four months or more before the spare parts arrived, by which time probably parts had been made in some local workshop, or the indenting unit had moved, and all trace of the indent was lost.

A special spare part store was therefore started at Havre R.E. Stores Depôt, and the E. and M. Companies, on their formation, were made the sole channel for the Armies through which spares could be obtained. The E. and M. Companies kept an Army spare part store, and were allowed to keep moderate stocks of spares for machines in use in the area. The system worked well, and the spare part store at Havre became a very efficient organization.

Spares were classified under two headings :—

"*A*" spares, which were small items commonly required, such as piston rings, valve springs, etc., and

"*B*" spares, which were larger spares, not so frequently required.

With each contract for a machine, a selection of "*A*" and "*B*"

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spares was ordered, the former being packed with the machine, and accompanying it to the Army when issued ; the latter being retained at Havre and only obtainable on indent. E. and M. Companies were empowered to indent direct on the Havre store.

Registration. Each E. and M. Company was responsible for keeping a record of the machinery in its area. The system under which this was done is described in a separate volume dealing with Machinery and Workshops, as is the question of machine repairs.

29. *Experience in other Theatres of War.*—It is an interesting fact that reports from Palestine, Salonika and Mesopotamia, agree very largely with the conclusions arrived at in this chapter. There is a natural diversity of opinion on the merits of certain engines, whose utility depended greatly on the skill of the engine drivers ; but as regards the most generally useful forms of pumps and engines, supply of spare parts, etc., there is general agreement. The one outstanding difference is in the use of the airlift, which does not seem to have been developed outside France and Flanders.

30. *Boring Plant.*—The first boring plant bought was of the non-self-propelling type, and had to be moved by F.W.D. lorries or gun tractors.

In the case of some drills made by Isler and Co., a horizontal portable boiler was provided independent of the drill (see *Photo* XIV.).

The types adopted later were imported from the United States, and were of " Keystone " and " Star " make, and were self-propelling (see *Photo* XV.).

The Isler drills referred to above were not strongly enough built to stand the work in this country, and required much alteration and strengthening. They afterwards did some good work.

The " Keystone " and " Star " drills were satisfactory so far as boring operations went. Of the two, the " Keystone " was the more suitable for forward work, being lighter and easier to handle ; one fault was common to all classes of drills used, namely—weakness of wheels and axles. The conditions as regards moving were particularly onerous, and long distances had to be covered over rough roads and pavé. The result was that broken wheels and axles were very common, and led to many unfortunate delays.

The majority of holes put down were for 6-inch casing, but latterly there was a strong tendency to use 8-inch casing on account of the fact that 6-inch holes would not permit the use of a satisfactory type of 3,000 g.p.h. pump. On the whole it seems advisable that 8-inch diameter holes should be used, as the cost is only slightly more, and there is little difference in the rate of drilling.

The amount of work done by the five Army Boring Sections and the Australian E. and M. Company Section, may be judged by the fact that over 470 bores were put down of depths varying from about

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200 feet to about 700 feet. Some remarkably good rates of drilling were achieved, over 100 feet being bored in several instances in the chalk in a day of two eight-hour shifts. As a rough guide it may be said that it took about four days to complete a 350 feet bore, when once the machine had been got to the site.

The types of boring tools supplied are shown on *Plate* XIV. These should be taken as types only, as the dimensions are not in all cases correct.

The rotary drills were for use in the clays of the Northern area, and were worked with a water flush.

A small really portable drill that could be used near the front line would have been of great value. A suggestion has been made of a light drill to be mounted on a whippet tank, and is worth consideration.

Photograph XVI. shows drilling machines ready for the road during the final advance in October, 1918.

31. *"Ashford" Tube-Well Strainers.*—In the Second Army Area (Flanders) little use could be made of bores, owing to the difficulties experienced in preventing "surging" in the very fine sands, which found their way through most of the filters used, and remained in suspension for several hours before settling in the storage tanks.

About the middle of 1918 this difficulty was overcome by the introduction of the "Ashford" filter tube, and experiments carried out by the Army Boring Section showed that the delivery of clear water was increased by at least fifty per cent. when the "Ashford" strainer was used. A section of the experimental deep-well bore, and details of the strainer, are shown on *Plates* XV. and XVI. This strainer, which had already been used by Mr. Ashford with great success in India, consisted of an octagonal column of rods kept in place by steel rings, and wound round on the outside with copper wire, each wire being a fraction of an inch from its neighbours.

Owing to the rapid advance and subsequent end of operations, investigations were not pursued, and it is probable that far greater results would have been obtained in time, as the efficacy of the filter depends mainly on the exact winding of the wire armature to suit the particular size of sand encountered.

During 1917 and 1918 investigations were continued into the nature and levels of the Thanet sands. Bores were sunk on a regular system in back areas, from which it was possible to plot the contours taken by the sands. These are shown on *Map* B.

32. *Mechanical Filters.*—A few mechanical filters were in use. These, as ordered by the Engineer-in-Chief, were of two capacities :—

(*a*) Small plants similar to those on the Water Tank Company sterilizing lorries, with Wallace & Tiernan liquid chlorine apparatus—capacity about 1,000 g.p.h. Though not bought for the purpose, these were actually used on Nos. 1 and 2 Water Tank Companies'

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lorries in place of the bleaching powder sets, the latter being taken off the lorries and used as stationary plants.

(*b*) Mechanical filters with a duty of 6,000 g.p.h. were used in one or two instances in the Northern Armies, where water was taken from the canals. These were made by Mather & Platt, and by United Water Softeners, Ltd. An example will be found in the report on Haringhe Water Supply (chap. III, para. 38).

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Chapter III.

WORKS.

33. *General.*—The main difficulty in Water Supply, both in advance and retreat, was found to be the supply for animals. The supply for regimental water-carts was a less serious problem.

For advancing over the dry chalk plateaux south of Arras, motor transport played a very large part in supplying both men and horses, until new sources of supply could be established. It was therefore of the utmost importance to establish new sources as quickly as possible, and only the most temporary kind of work could be done. In fact in all work in advance or retreat, the installations were of a very temporary nature, and were gradually improved as the situation became stable. In the advance beginning in August, 1918, the available means of water transportation was increased by the use of ordinary 3-ton lorries with a 16 ft. × 16 ft. sheet inside (see *Plate* XVII.). About 500 gallons per lorry were carried by this means.

In trench warfare the work was done in the first place on a more permanent basis.

The following paragraphs give a few general particulars of types of work done.

34. *Water Points.*—Water points were as a general rule sited near, but *not* on, important roads, the sites being determined according to the topographical features. In dry weather, cross-country tracks were used as far as possible for horses.

In addition to the congestion caused on main roads by horses waiting to water, the wear and tear of the roads themselves, due to horses going to and from for water, was found to be very great. It was therefore important to site the water points so that they could be approached in wet weather by side roads, and without crossing main traffic routes.

Water points consisted in the main of :—

(*a*) Storage reservoirs.
(*b*) Horse troughs and standings.
(*c*) Lorry and water-cart standpipes.
(*d*) Water-bottle filling apparatus.

(*a*) *Reservoirs.* For temporary work, the 2,300-gallon canvas tank as supplied by Ordnance was largely used. This was placed on the ground, the sides being supported by wooden frame work.

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When larger capacity was required, tarpaulins and sailcloth covers were used. The most common size of cover used was 30 ft. square, which forms an excellent reservoir 2 ft. 6 in. deep, holding about 8,000 gallons nett.

As many of these were used as necessary, the different reservoirs being coupled up with a 4-inch pipe. These were also supported by wooden side frames.

A number of different types of frame were used according to the designs of the various Water Supply officers and Army Troops Companies, but finally it was agreed to standardize one type and make it into a supply from the Base for stock in R.E. Parks. The details of this are shown on *Plate* XVIII. It will be noted that the same panel can be used to form a frame either for the 2,300 gallons, or the 8,000 gallon reservoir.

For more permanent work the pressed steel plate tanks (see para. 17, chapter II.) were sometimes used, but far more commonly, the sailcloth covers.

These were used in several ways :—

(i.) As single sheets with timber framing set on the ground, or on staging to any height required.
(ii.) As single sheets, banked round with earth.
(iii.) Two or more sheets joined and banked round to form larger reservoirs.

In this case the joint was made as shown on *Plate* XVIII.

All the above methods were satisfactory.

The life of the sheets was very much improved by tarring well on both sides. In a few cases brick or concrete reservoirs were used.

The advantages of having adequate storage is very great since it enables unforeseen contingencies such as pump breakdown, breakages of pipe line, etc., to be tided over without serious interruption to the service. Storage of from 40,000 to 60,000 gallons, and in some cases more, was frequently provided at water points (see *Plate* XIX.).

(*b*) *Horse Troughs and Standings.* In concentrations it was not possible to provide separate water points for each unit on a piped system.

Common water points are not conveniently made larger than what is necessary to water 2,000 horses per hour, in lots of 170 every five minutes. This requires about 180-ft. run of double side troughing as 10 to 12 horses per foot run can water per hour.

All troughs require standings of timber, road metal, or other hard material, and to be protected from pressure by a stout guard rail each side.

Water discipline is of the highest importance, and cover is required for the permanent police, where also a daily record can be kept of the units, times, and numbers of horses watering.

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The gravity main from the reservoir was normally 4-inch, with 2-inch feed pipes to the troughs, the feed pipes being boxed to prevent horses' bridles catching on the pipe.

A great variety of types of horse troughs were used, such as 600-gallon canvas troughs as issued by Ordnance, troughs made of corrugated iron, sheet iron, wood, rotproof canvas, tarred roofing felt, reinforced concrete, etc.

For first-aid work the 600-gallon canvas trough was mainly used, and was satisfactory when surrounded by a stout rail to prevent horses stepping in it. The stands supplied with the trough were unsatisfactory, and were seldom used. Of the other types, many were poor owing either to small storage capacity, labour and expense in making, or short life.

It was decided in 1918 to standardize one pattern of sheet metal trough of large capacity, and the type shown on *Plate* XX. was designed at the Base. This was not thoroughly tested in practice, owing to the cessation of hostilities.

Photo XVII shows a typical horse water point in the Ypres district.

(*c*) *Lorry and Water-cart Standpipes.* These do not present any special features. For lorry filling about nine feet of head room is required, and the hose should be of such a length that it does not drag on the ground and get fouled with mud. The standpipes should be far enough apart to allow a lorry with water-cart trailer to fill without interfering with the next standpipe.

Water-cart. Construction of water-cart filling points generally followed the lines of *Plate* XXI. The filling point was off the main road, with "in" and "out" entrances. A waiting point was sometimes provided when on an important traffic route, or where used by a very large body of troops.

Main water points should generally be able to deal with six or eight carts at once.

Chlorination is done in the water-carts, a notice being fixed in a permanent position stating the number of "scoops" required per water-cart.

(*d*) *Water-Bottle Filling Apparatus. Photo* XVIII. This consisted as a rule of two 200-gallon or 400-gallon tanks connected to a water-bottle filler (see para. 17, chapter II.), so that they could be used alternately. When one of the tanks was emptied, it was refilled and bleaching powder added as necessary. During the time the second tank was being drawn on, the water in the first was chlorinating.

Photo XIX. is a typical water point in the Ypres area.

35. *Local Water Points.*—On *Plates* XXII. and XXIII. is shown a method of impounding springs, or water, to establish small local water-cart filling points, that proved both useful and effective.

The guard or cradle placed upon the G.S. lift and force pump was

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found to be of great value. Without this feature a G.S. pump was usually broken or worn out in a fortnight or three weeks—the cradle increased its life to eight months. This was the longest period over which such a cradle was watched, and the pump was still in good working order.

The two blocks were placed quarter inch short of the full stroke each side, and so saved the jar or bump on the bearings and bolts. The pump therefore became practically foolproof against the most inexperienced handling.

36. *Trench Filling Points.*—These were often constructed to have a capacity of 400 gallons of storage, preferably in two 200-gallon tanks. This allowed water to be drawn at all times of day when the pipe line was cut by enemy shell fire.

A general type of these Trench Filling Points is shown on *Plates* XXIV. and XXV.

It was not found necessary to have automatic (ball-valve) control in filling these points, as troops in the line could usually be depended on to be careful in keeping the tanks full whenever possible, and in not allowing waste to occur after the tanks were full.

When there was no pipe line to the trenches it was found that storage was better effected by means of 2-gallon tins, rather than in tanks. These tins were usually sent up at night with rations. Depôts where tins could be filled, and exchanged for the empties brought back from the trenches, are necessary—they are conveniently sited near the point at which rations for the trenches are issued.

The essentials for such a depôt are :—

(*a*) *Storage.* Sail-cloth reservoir on adjacent higher ground if available, or elevated tank of about 3,200 gallons, giving a gravity feed with sufficient head for rapid filling. The supply pipe to deliver to :—

(*b*) *Chlorinating Tanks.* Two are required, 400 to 800 gallons each so that one may rest while the other is in use. These are connected with :—

(*c*) *Draw off pipe* fitted with taps, from which the tins are filled Drainage is normally provided below the taps, and a standing made of trench boards.

(*d*) *Cleaning Shed.* One of two taps over some troughing which has an outlet pipe to a drain. Trench board standing. Dunnage provided in the shed on which to store clean tins.

Arrangements are also required for regulation of transport, whatever it may be—tramway, G.S. wagons, pack-mules, or carriers ; and also for a small permanent staff.

When tanks are fixed in the trenches they require lids as protection against the splash of gas shells, which poison the water.

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37. *Purification.*—It was a standing rule that all water, not specifically exempted by the medical authorities, should be chlorinated before use. The standard practice was to chlorinate at the water point, and not at the source of supply.

The special provision for mobile plant on barges and lorries has already been described (see chapter 1, para. 4 and 5.).

A common arrangement for a small local water point is shown on *Plate* XXVI., consisting of two tanks used alternately.

French Practice. At different times a number of water points were taken over from the French Army. They used a purifying solution known as "Eau de Javel." The methods of using this are shown on *Plate* XXVII. (non-automatic) and *Plate* XXVIII. (automatic); the latter method was found to be too delicate for use during winter frosts.

Sedimentation. In addition to chlorinating processes to destroy bacteria, it is sometimes necessary to remove suspended matter first. The usual process consisted of precipitating the suspended matter by the addition of alum, followed by chlorination of the clear water, as follows:—

The alumino ferric (common alum) is made into a solution, which is allowed to drip into the in-coming stream of water pumped into the settling tank. A white gelatinous precipitate of alumino hydroxide is formed, and this sinking to the bottom of the tank carries with it the suspended matter in the water. About eight hours or less is usually ample for the complete sedimentation of suspended matter.

The clear supernatant water in the settling tank is then pumped into the chlorinating tank and the solution of bleaching powder allowed to drip into the in-coming stream in the same way as the alum solution.

The chlorinating tank is provided simply to act as a reservoir, and in order to ensure the 30 minutes' contact necessary for efficient chlorination. The chlorinated water is then pumped to water-carts or to elevated tanks at the water point.

The points to be observed for satisfactory working are as follows:—

(*a*) The alum solution must be made up of the requisite strength as found by experiment, and added as evenly as possible to the in-coming crude water—it is better to add too much than too little.

(*b*) The in-coming crude water, after the addition of alum, should be made to flow along one side of the settling tank with a certain degree of force, so as to produce a "swirl" round the tank; this induces satisfactory sedimentation. The "swirl" is easily produced by leading the water in along a trough inclined to the horizontal.

(*c*) The water in the settling tank must be allowed to stand until all the suspended matter has settled to the bottom, and the water level should not be pumped lower than six inches from the bottom.

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(*d*) When pumping from the settling tank to the chlorinating tank, water should be taken for as long as possible from at least six inches below the surface.

(*e*) Adequate mixture of bleaching powder solution and unchlorinated water must be arranged. This is done by running the two together down a trough, in which baffles are fixed, into the chlorinating tank at the rate of flow in accordance with the Tables given on *Plates* XXIX. and XXIXA.

(*f*) In the case of crude waters which give an acidic reaction, some alkali such as milk of lime must be added, in order to secure proper precipitation. This is done at the same time and in the same way as the alum solution.

(*g*) Wash out sludge from the settling tank at intervals. *Plate* XXX. shows in diagrammatic form the standard arrangement, and *Plate* XXXI. details of fittings as made in the Army workshops.

38. *Haringhe Water Works.* (*Plate* XXXII.).—Probably the most ambitious scheme of a semi-permanent nature for the supply of pure water to a large area was that undertaken at Haringhe on the River Yser during 1917. The work, which was begun about the end of April, was designed to supply 200,000 gallons per day of filtered and chlorinated water from the Yser under ordinary conditions of the river.

It comprised the construction of:—

(*a*) Collecting—or settling tank of a capacity of about 100,000 gallons.

(*b*) Two pre-filters (30 ft. × 20 ft.) of shingle, arranged in parallel.

(*c*) Two filters (60 ft. × 30 ft.) of gravel and sand, arranged in parallel.

(*d*) Storage—or clear water tank of 100,000 gallons capacity. (See *Plate* XXXII. and panoramic *Photo* XX.).

A fixed mechanical filtering and sterilizing plant of 6,000 gallons per hour capacity was also ordered, to act as a stand-by, and to assist if necessary in dealing with the river under specially turbid conditions. (See *Photo* XXI.).

In the collecting tank it was expected to obtain a certain amount of preliminary sedimentation. From the collecting tank the water passed through the gravel roughing filters, being chlorinated by an automatic feed liquid chloride of lime apparatus before finally passing into the storage tank.

In designing the filters it was intended that each half should be independent, and not to filter more than 5,000 gallons an hour, which would allow eight hours for each half of the filters being cleaned out on alternate days if required under the worst conditions.

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To allow the filters to be properly cleaned within the prescribed time, 2-inch branch pipes were taken off the pumping main to standpipes along each side of the filter beds. To each standpipe 2-inch armoured hose pipes were attached fitted at the other end with a hollow steel lance perforated at the pointed end with fine holes. With the pressure of water in the pumping main, the accumulated sludge was expected to be blown rapidly out of the filters by systematic probing through the sand and fine gravel, the sludge thus removed being allowed to drain off at the grit pit specially provided at each filter chamber for the purpose.

When the works were opened it was soon found that the crude river water, containing a variable and considerable amount of finely divided suspended matter, together with organic matter, rapidly choked the sand filters, so that the calculated flow could not be maintained. The actual demands for water also exceeded the original 200,000 gallons per day allowed for. It was also proved that sand filtration alone did not remove the colour or the taste from a water so highly contaminated as was that of the river Yser; so it was decided to put in preliminary sedimentation tanks, using alumino ferric as a coagulent to assist the sand filtration.

Four standard 50,000 gallon tanks were completed by an Army Troops Company within 10 days (see *Photo* XXII.), and the filters were gradually re-fitted with more finely graded and cleaner sand and gravel, supplies of which had throughout been a great difficulty.

While this work was in progress 10 sterilizers and three de-poisoners of the 2nd Water Tank Company were brought up, and working 16-24 hours a day supplied daily average of nearly 120,000 gallons of pure water.

The complete lay-out of the works is shown on *Plate* XXXII.

Photo XXIII. shows the interior of No. 2 Pump-house, and *Photo* XXIV. the auxiliary steam pumps.

Photo XXV. gives a view of the intake arrangements.

Many miles of pipe line were laid from these works to forward water points.

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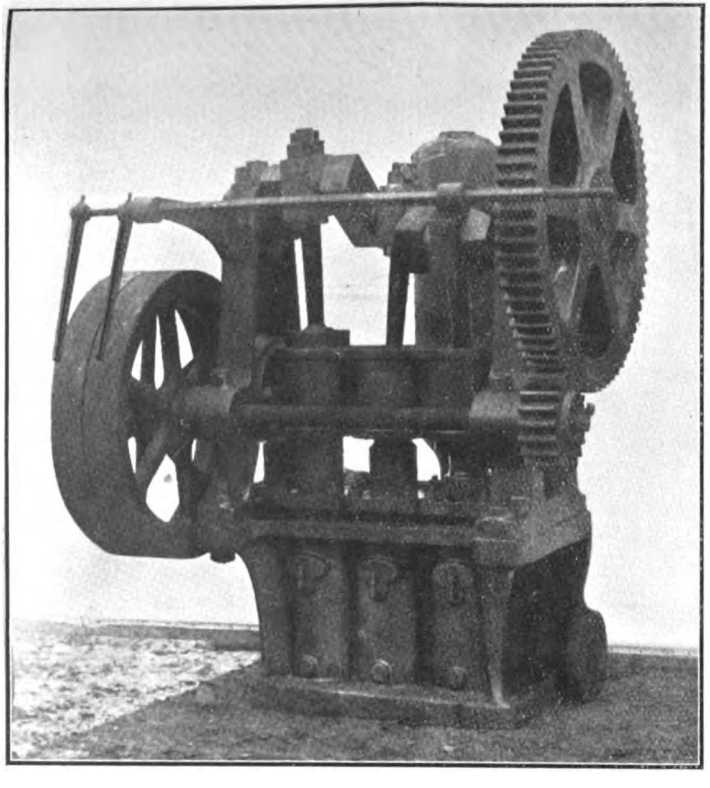
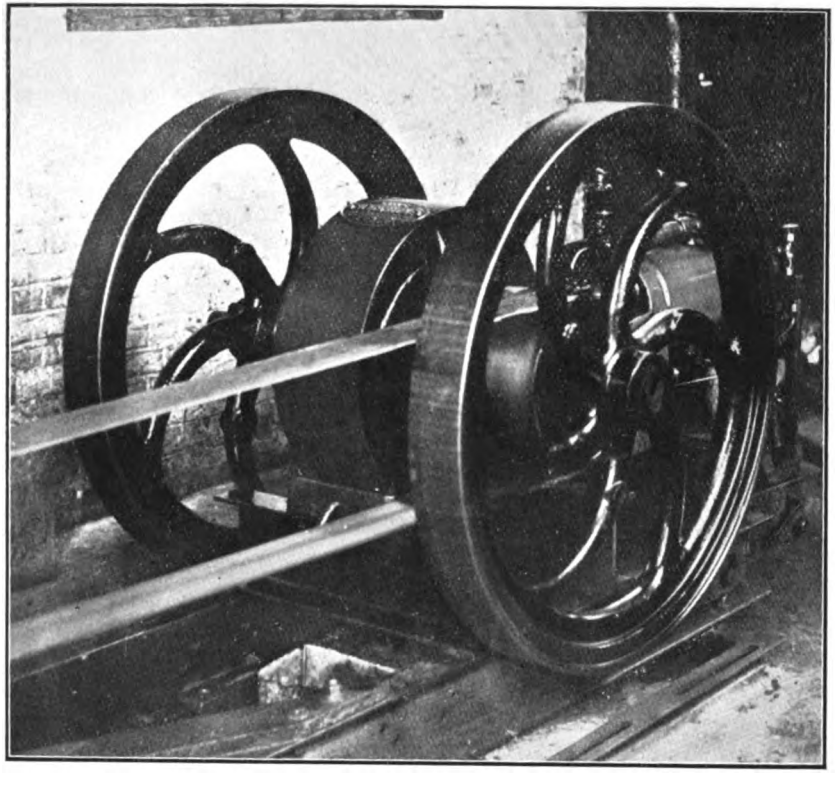


Photograph I.—Vertical Triple Ram Pearn Pump.



Photograph II.—Blackstone 7-H.P. Oil Engine.

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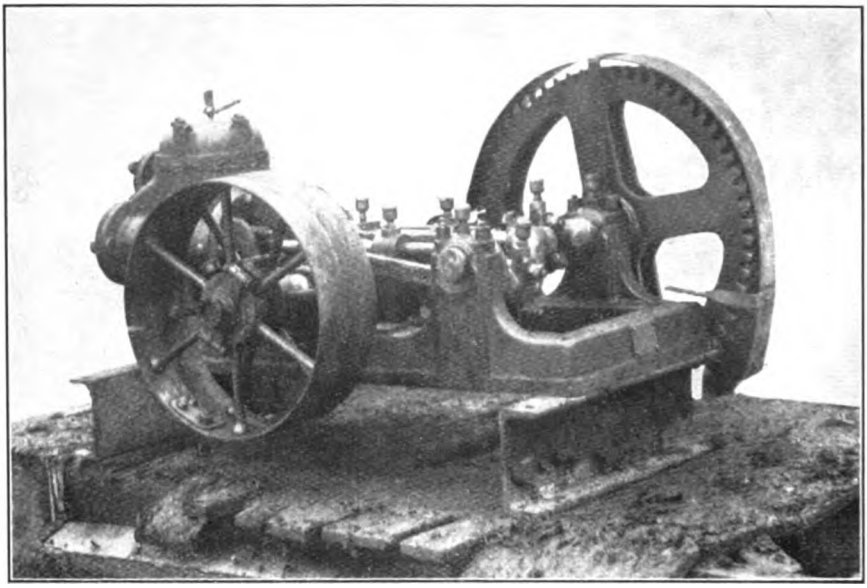
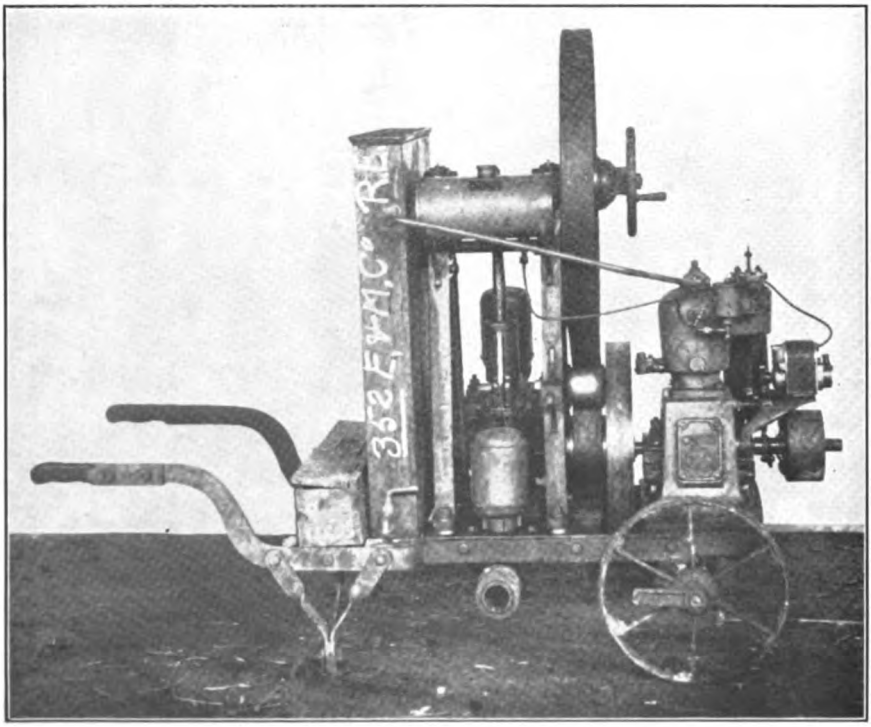


Photograph III.--Hayward—Tyler Pump.



Photograph IV.- Guy & Mital Single Ram Pump.

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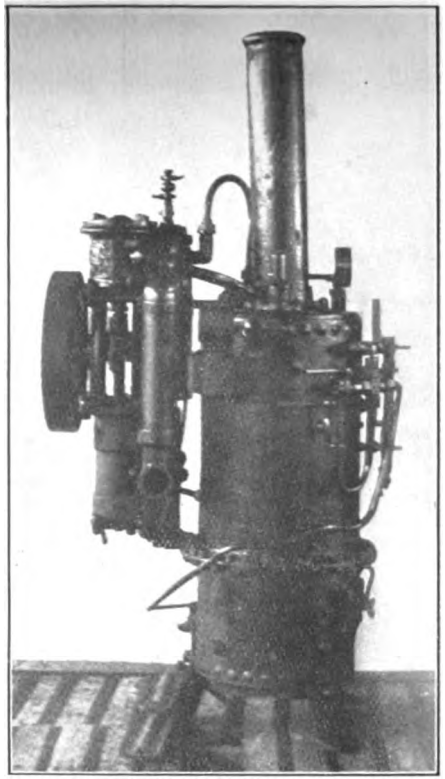
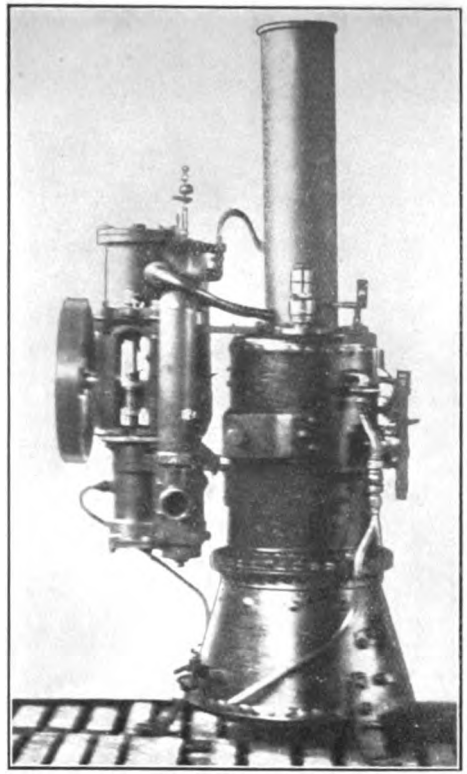
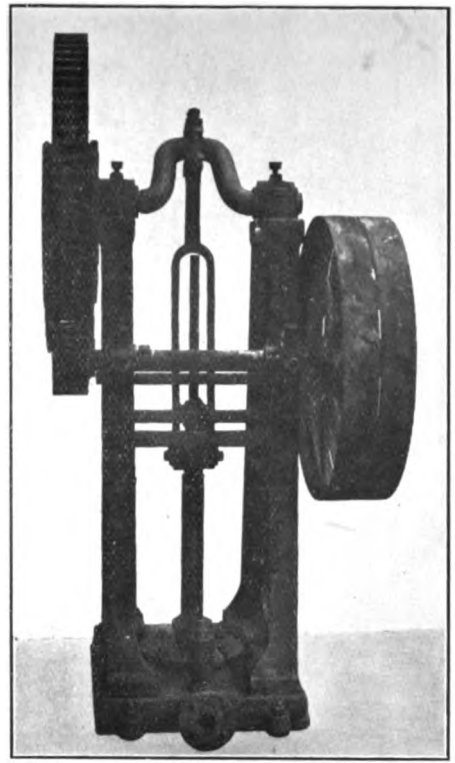


Photograph V.—No. 1 Merryweather Valiant Pump.



Photograph VI.—No. 2 Merryweather Valiant Pump.



Photograph VII.—Potter Tube Well Pump.

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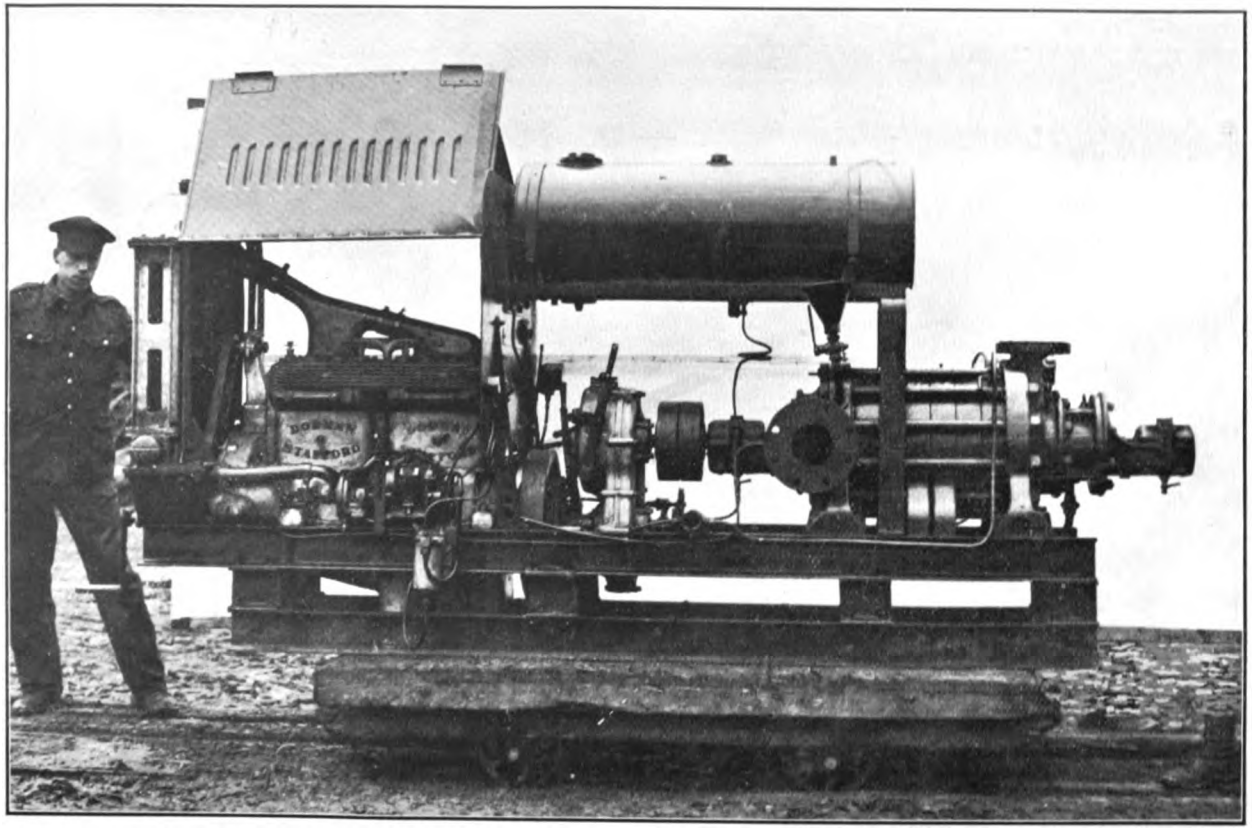

Photograph VIII.—Dorman—Mather & Platt Set.

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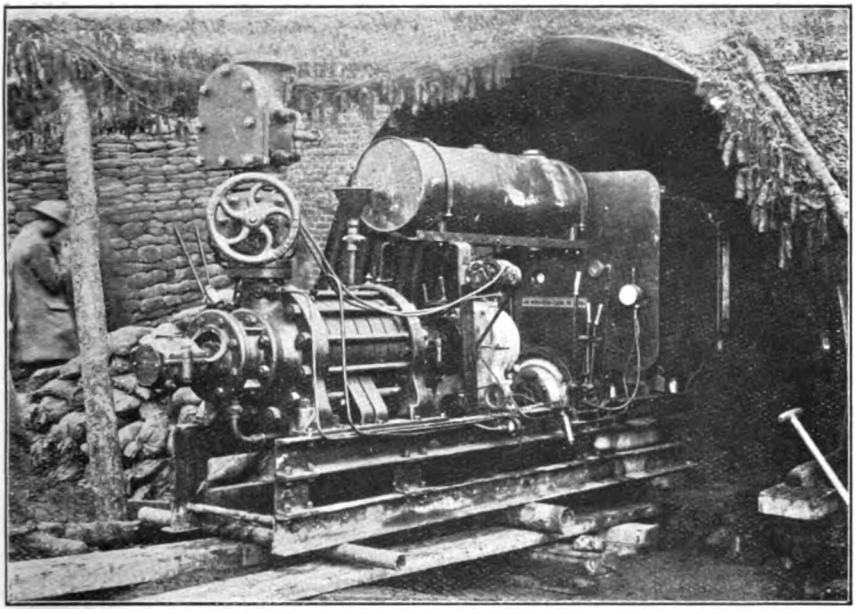
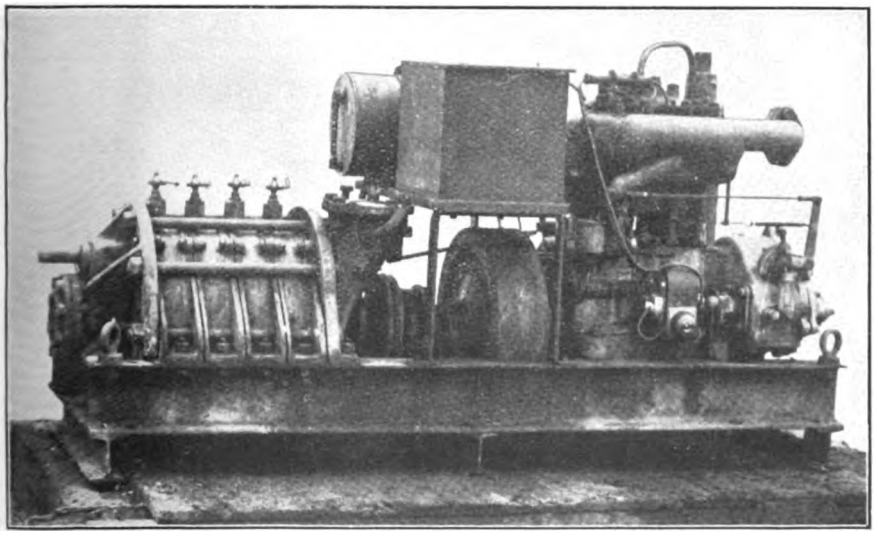


Photograph IX.—Dennis—Mather & Platt Set.



Photograph X.—Keighley—Gwynne Set.

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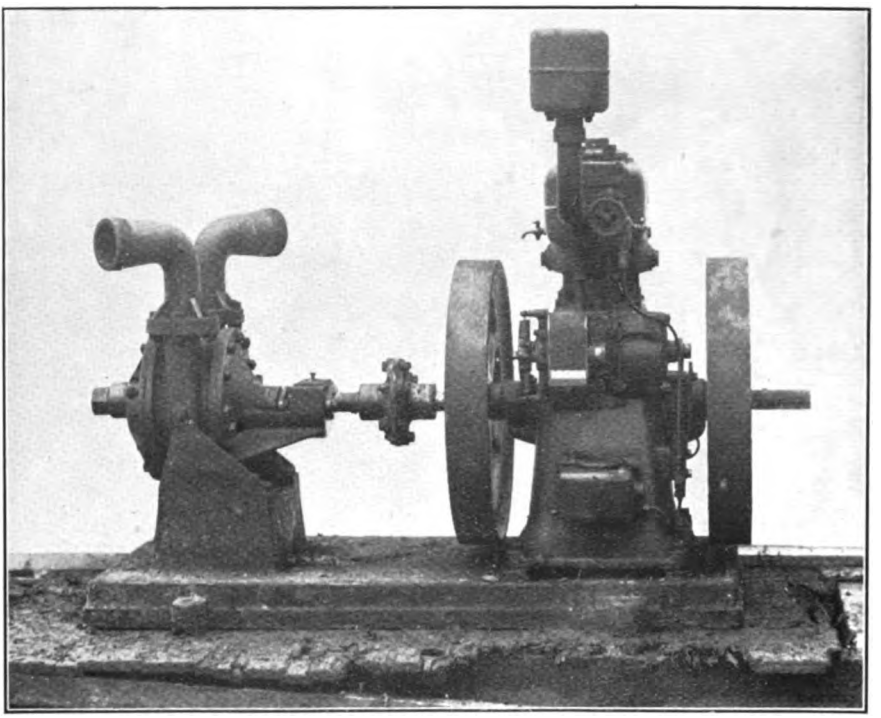
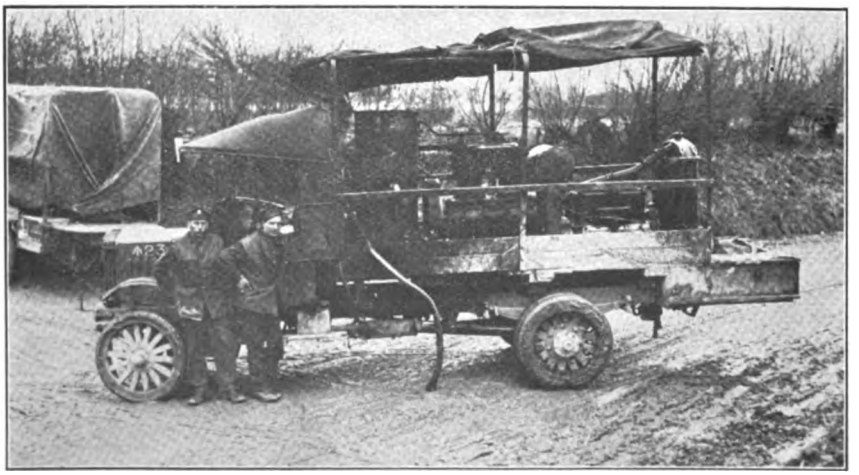


Photograph XI.—Roto Plunge Pump.



Photograph XII.—Compressor Lorry. Dorman—Lacy—Hulbert Set.

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Photograph XIII.—Compressor Lorry, De Dion–Broome & Wade Set.

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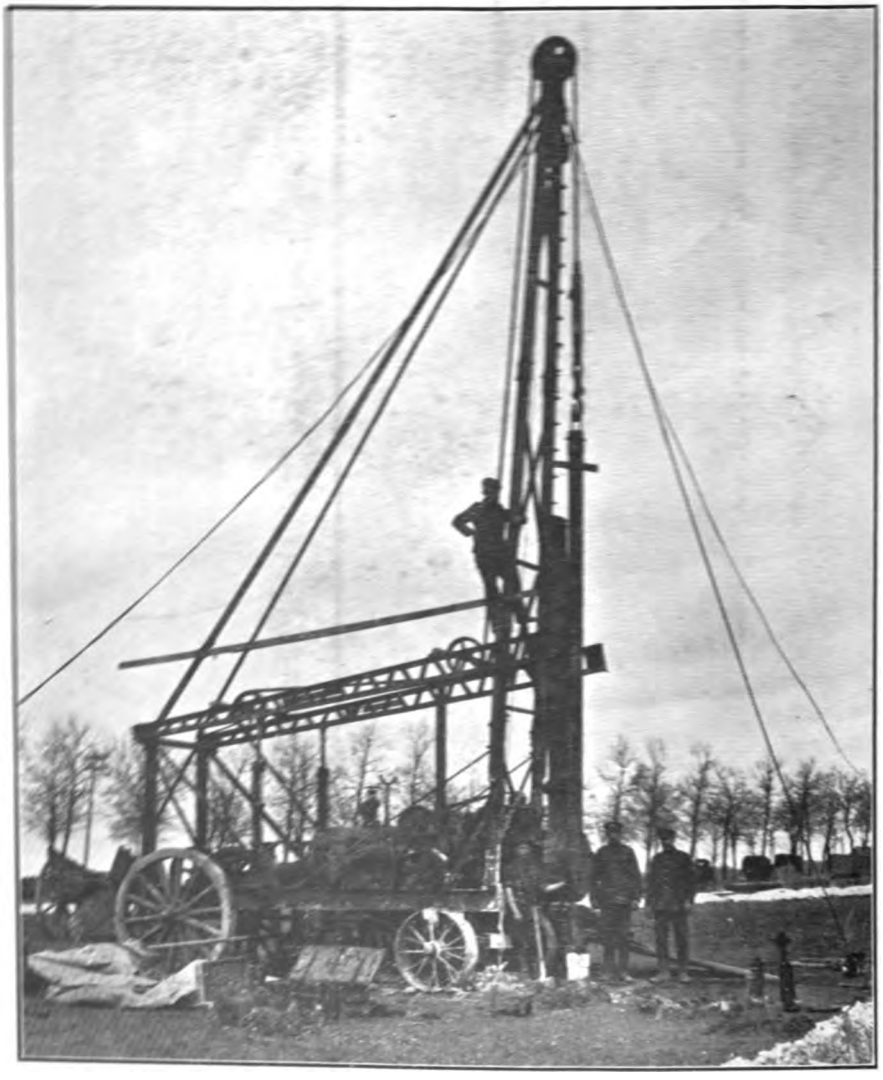

Photograph XIV.—Isler Drill.

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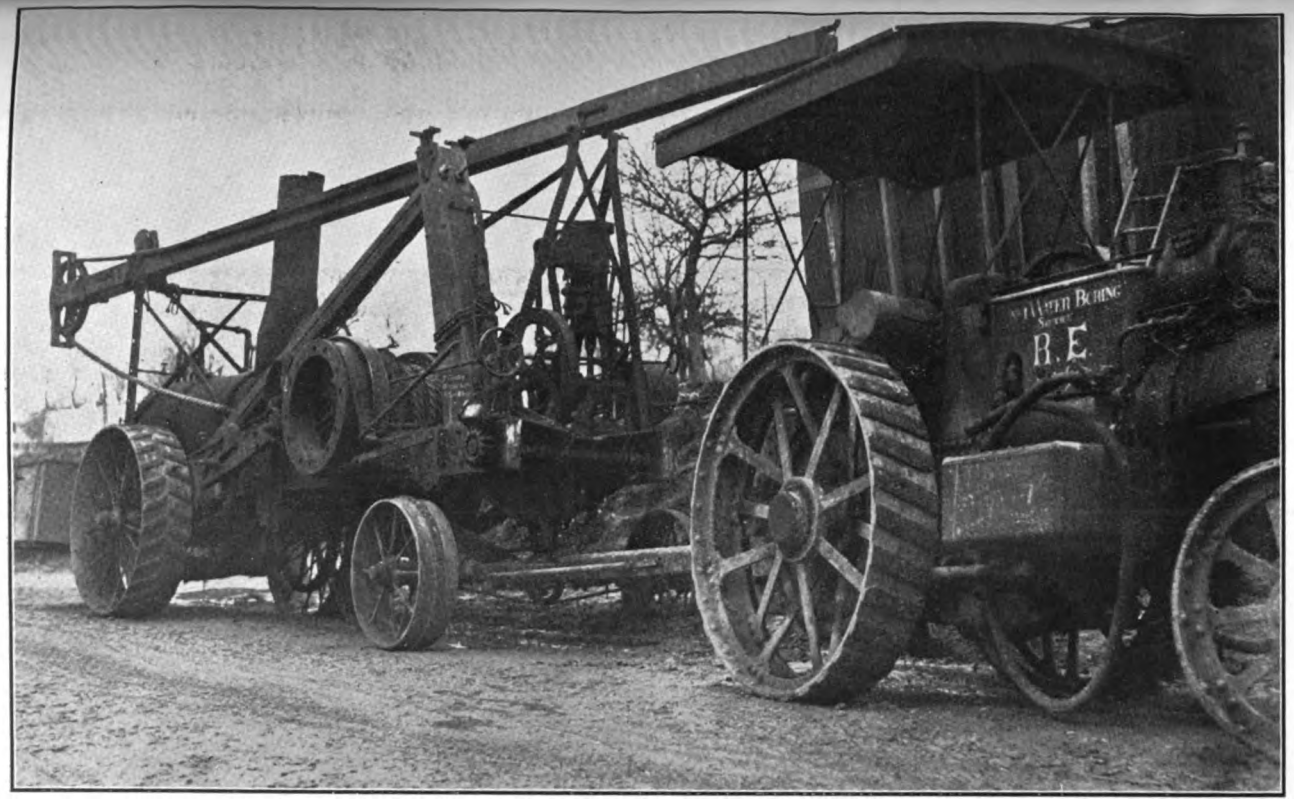

Photograph XV.—Star Tractor Drill.

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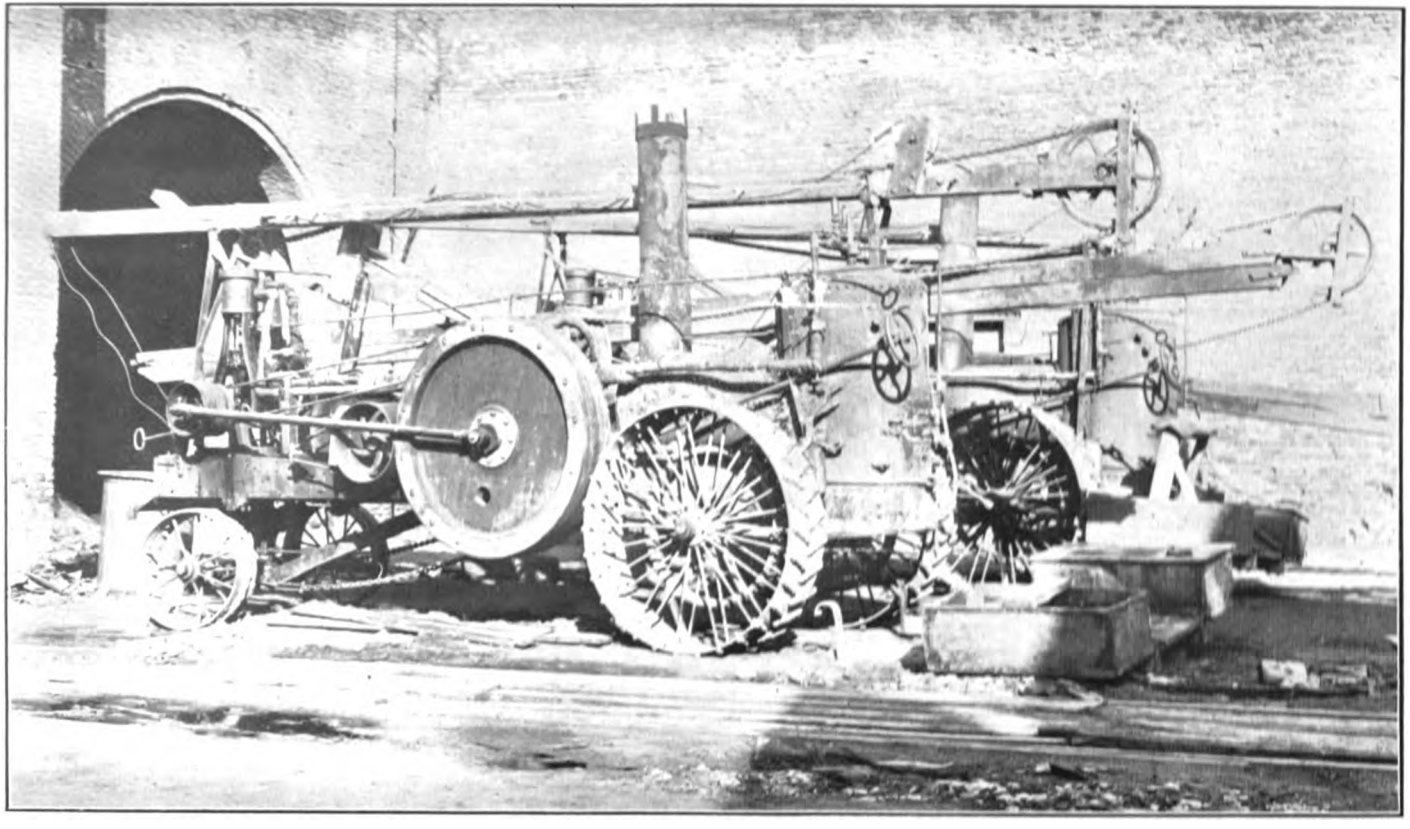

Photograph XVI.—Drills ready for the Road during 1918 Advance.

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Photograph XVII.—Horse Water Point.

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Photograph XVIII.—Filling Water Bottles.

Photograph XIX.—Typical Water Point in Flanders.

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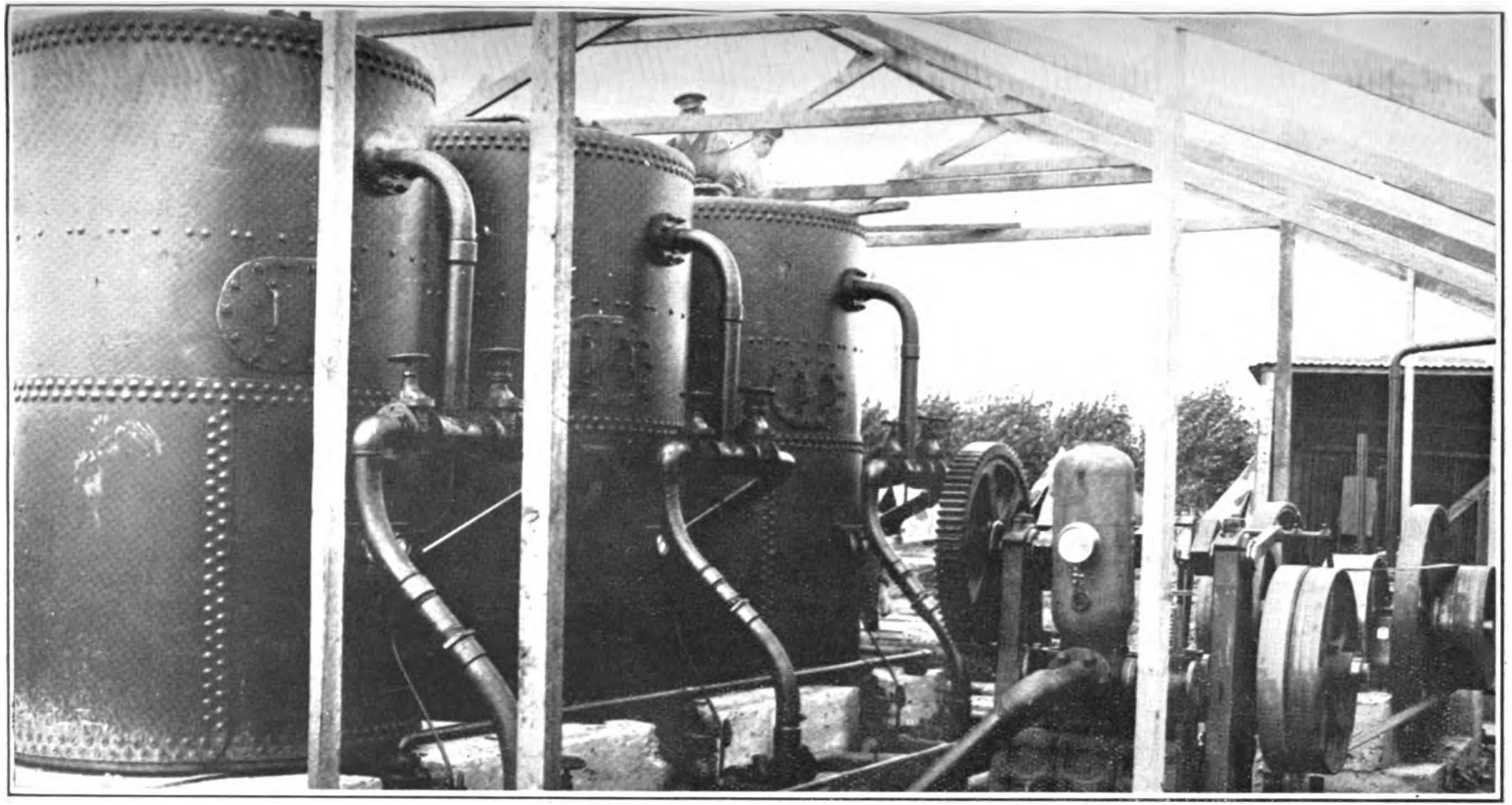

Photograph XXI.—Haringhe Waterworks. Mechanical Filtering Plant.

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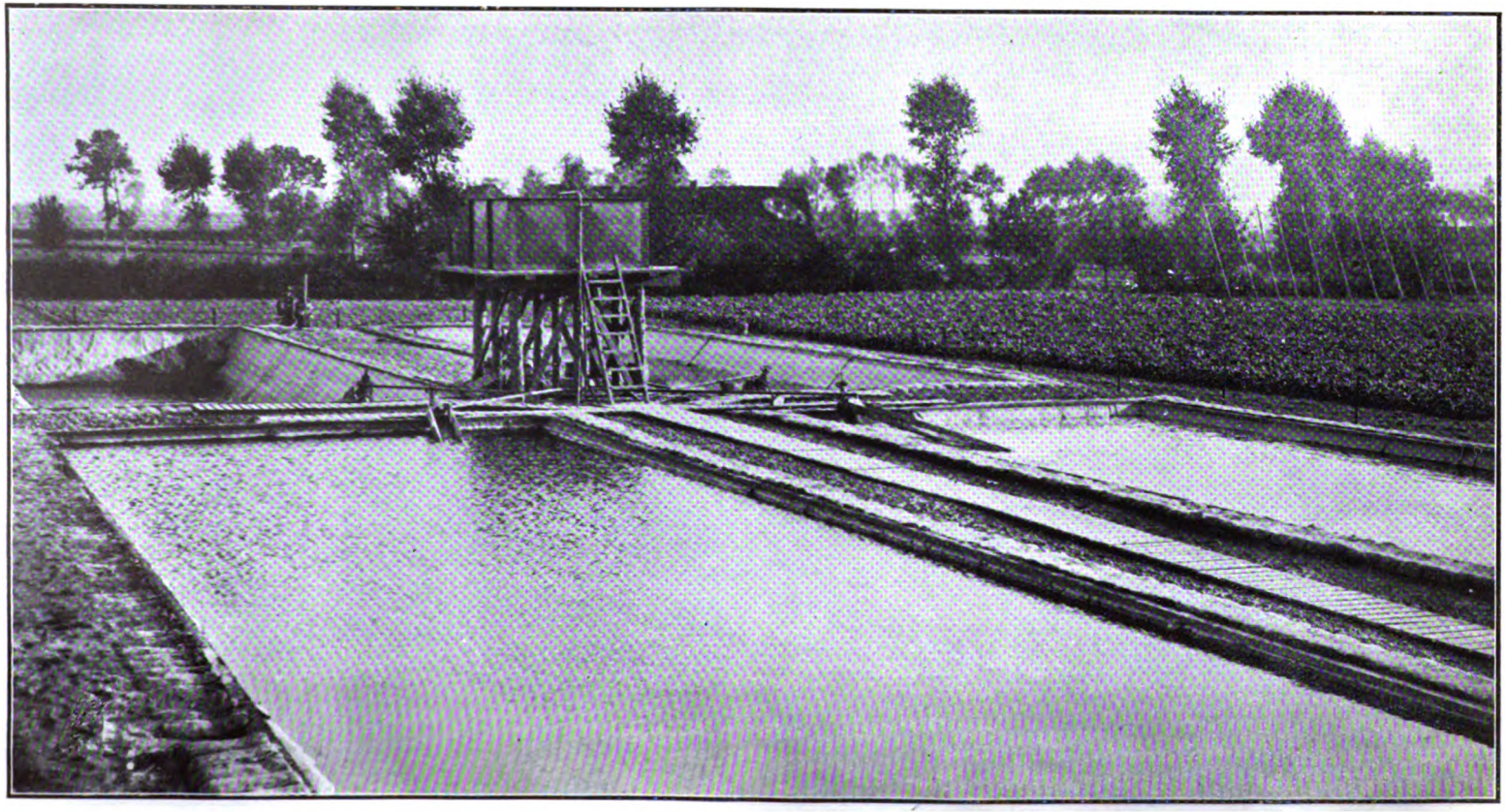

Photograph XXII.—Haringhe Waterworks. Sedimentation Tanks.

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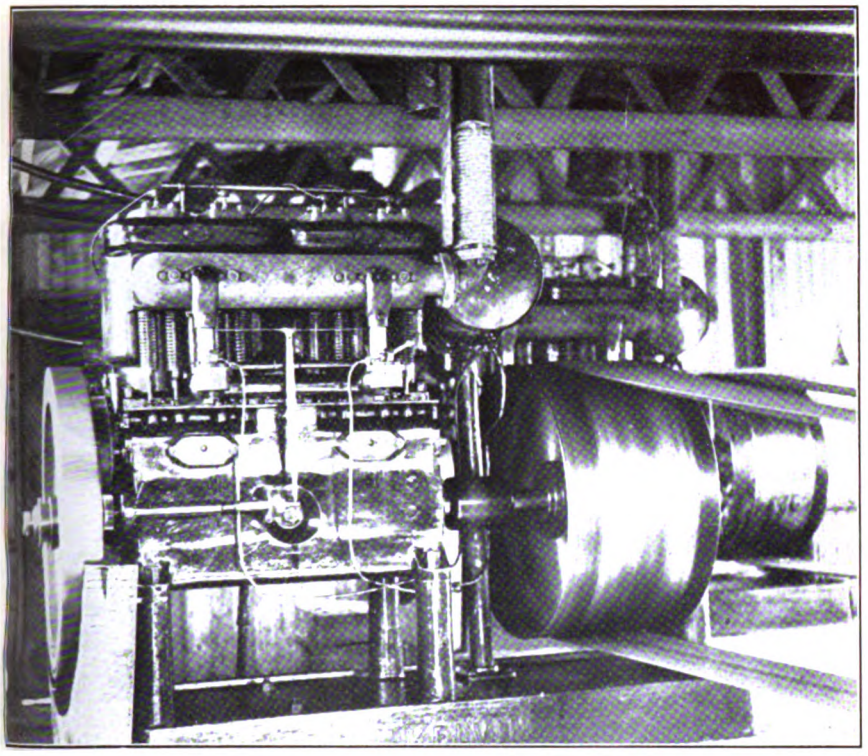
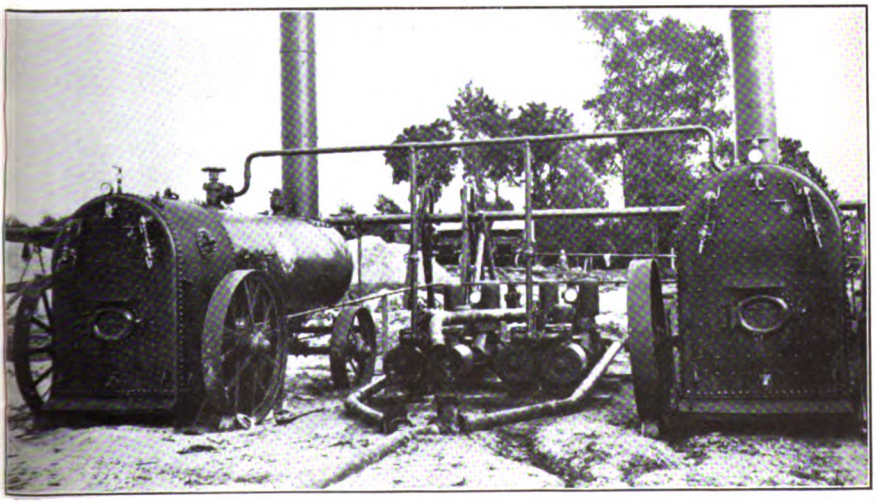


Photograph XXIII.—Haringhe Waterworks. Kelvin 60-H.P. Petrol Engine in Main Pump House.



Photograph XXIV.—Haringhe Waterworks. Auxiliary Steam Pumps.

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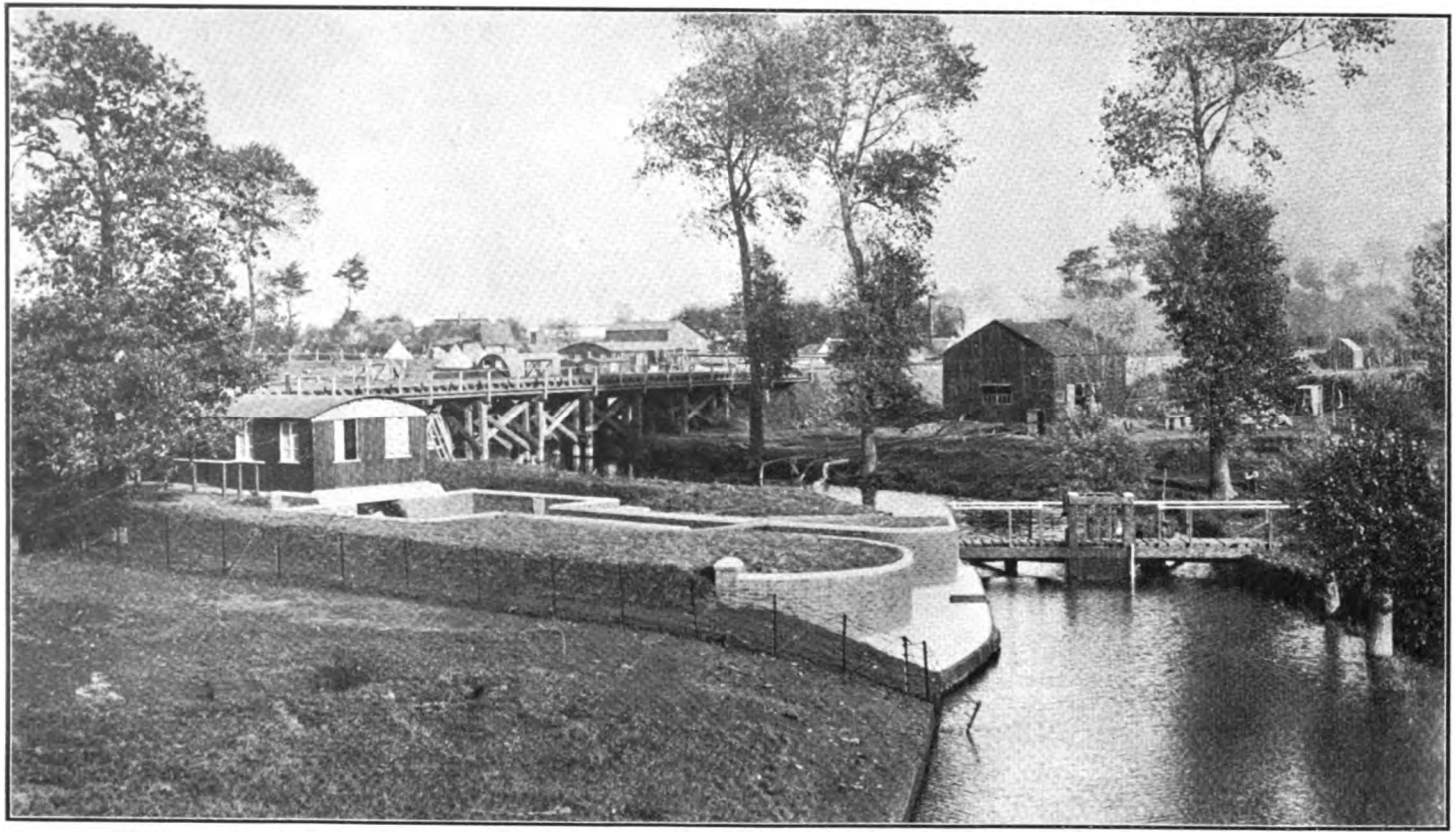

Photograph XXV.—Haringhe Waterworks. View of Intake.

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PLATE I.

GEOLOGICAL SKETCH MAP.

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GEOLOGICAL SECTION FROM OSTEND TO PERONNE.

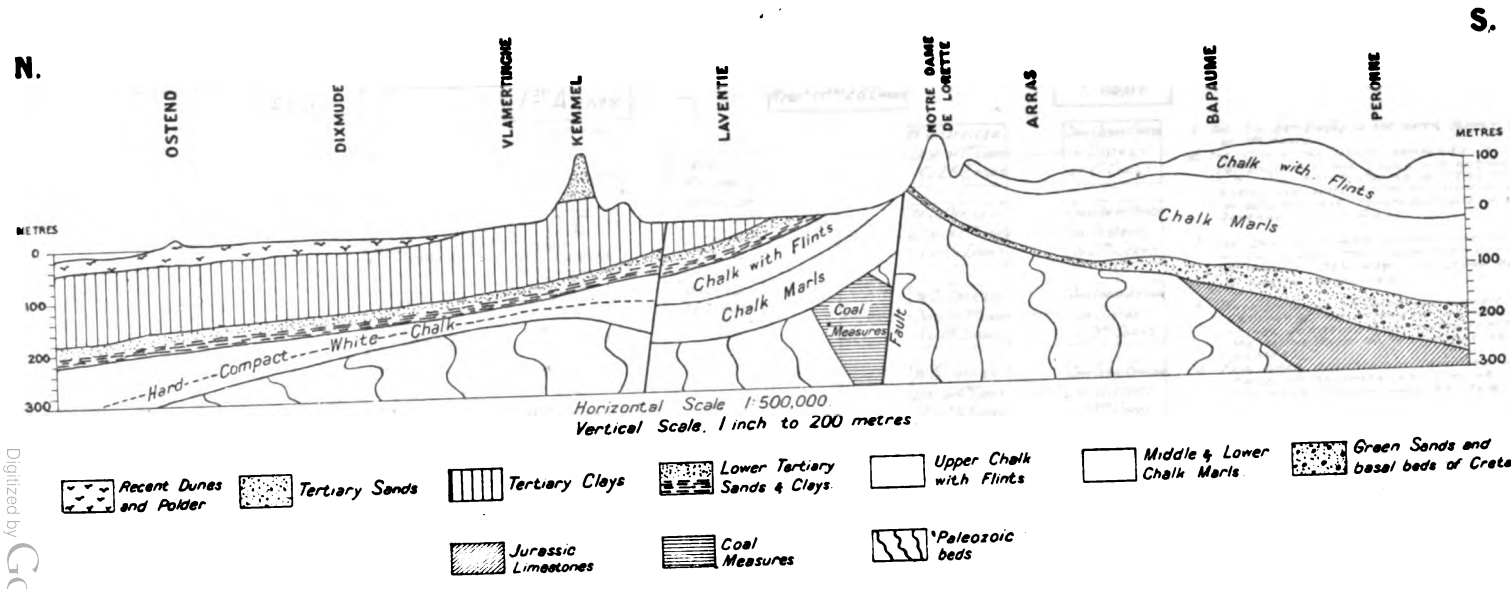

PLATE II.

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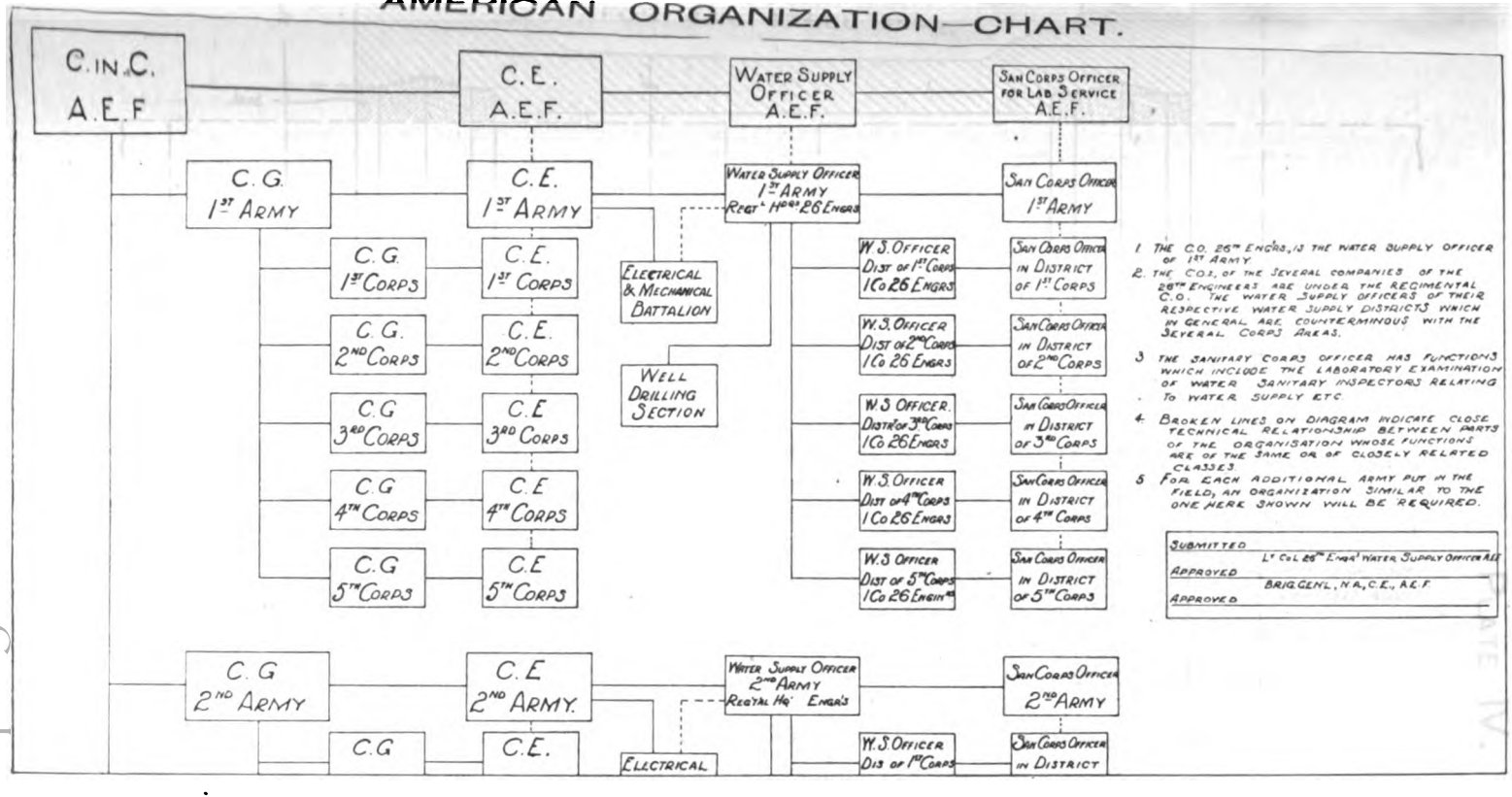
AMERICAN ORGANIZATION—CHART.


C. IN C. A.E.F
C.E. A.E.F.
WATER SUPPLY OFFICER A.E.F.
SAN CORPS OFFICER FOR LAB SERVICE A.E.F.
C.G. 1ST ARMY
C.E. 1ST ARMY
WATER SUPPLY OFFICER 1ST ARMY REGT'L HQRS 26 ENGRS
SAN CORPS OFFICER 1ST ARMY
C.G. 1ST CORPS
C.E. 1ST CORPS
ELECTRICAL & MECHANICAL BATTALION
W.S. OFFICER DIST OF 1ST CORPS 1 CO 26 ENGRS
SAN CORPS OFFICER IN DISTRICT OF 1ST CORPS
C.G. 2ND CORPS
C.E. 2ND CORPS
WELL DRILLING SECTION
W.S. OFFICER DIST OF 2ND CORPS 1 CO 26 ENGRS
SAN CORPS OFFICER IN DISTRICT OF 2ND CORPS
C.G 3RD CORPS
C.E 3RD CORPS
W.S. OFFICER DISTR OF 3RD CORPS 1 CO 26 ENGRS
SAN CORPS OFFICER IN DISTRICT OF 3RD CORPS
C.G 4TH CORPS
C.E 4TH CORPS
W.S. OFFICER DIST OF 4TH CORPS 1 CO 26 ENGRS
SAN CORPS OFFICER IN DISTRICT OF 4TH CORPS
C.G 5TH CORPS
C.E 5TH CORPS
W.S. OFFICER DIST OF 5TH CORPS 1 CO 26 ENGRS
SAN CORPS OFFICER IN DISTRICT OF 5TH CORPS
C. G 2ND ARMY
C. E 2ND ARMY.
WATER SUPPLY OFFICER 2ND ARMY REGTAL HQ ENGR'S
SAN CORPS OFFICER 2ND ARMY
C.G
C.E.
ELECTRICAL
W.S. OFFICER DIS OF 1ST CORPS
SAN CORPS OFFICER IN DISTRICT

1. THE C.O. 26TH ENGRS., IS THE WATER SUPPLY OFFICER OF 1ST ARMY.
2. THE CO.S OF THE SEVERAL COMPANIES OF THE 26TH ENGINEERS ARE UNDER THE REGIMENTAL C.O. THE WATER SUPPLY OFFICERS OF THEIR RESPECTIVE WATER SUPPLY DISTRICTS WHICH IN GENERAL ARE COUNTERMINOUS WITH THE SEVERAL CORPS AREAS.
3. THE SANITARY CORPS OFFICER HAS FUNCTIONS WHICH INCLUDE THE LABORATORY EXAMINATION OF WATER SANITARY INSPECTORS RELATING TO WATER SUPPLY ETC.
4. BROKEN LINES ON DIAGRAM INDICATE CLOSE TECHNICAL RELATIONSHIP BETWEEN PARTS OF THE ORGANISATION WHOSE FUNCTIONS ARE OF THE SAME OR OF CLOSELY RELATED CLASSES.
5. FOR EACH ADDITIONAL ARMY PUT IN THE FIELD, AN ORGANIZATION SIMILAR TO THE ONE HERE SHOWN WILL BE REQUIRED.

SUBMITTED
Lt Col 26th Engrs Water Supply Officer A.E.F.
APPROVED
BRIG. GENL., N.A., C.E., A.E.F.
APPROVED

PLATE III.

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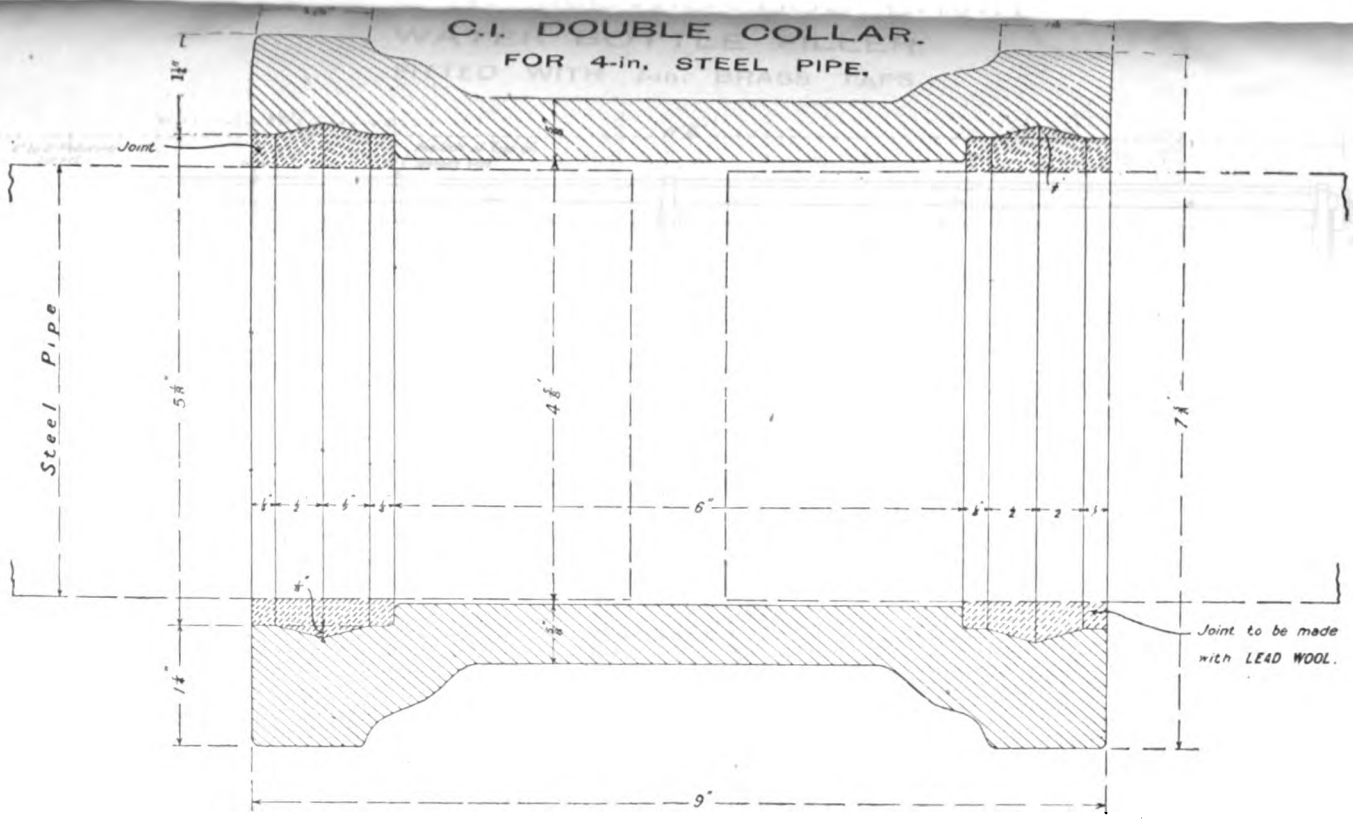

PLATE IV.

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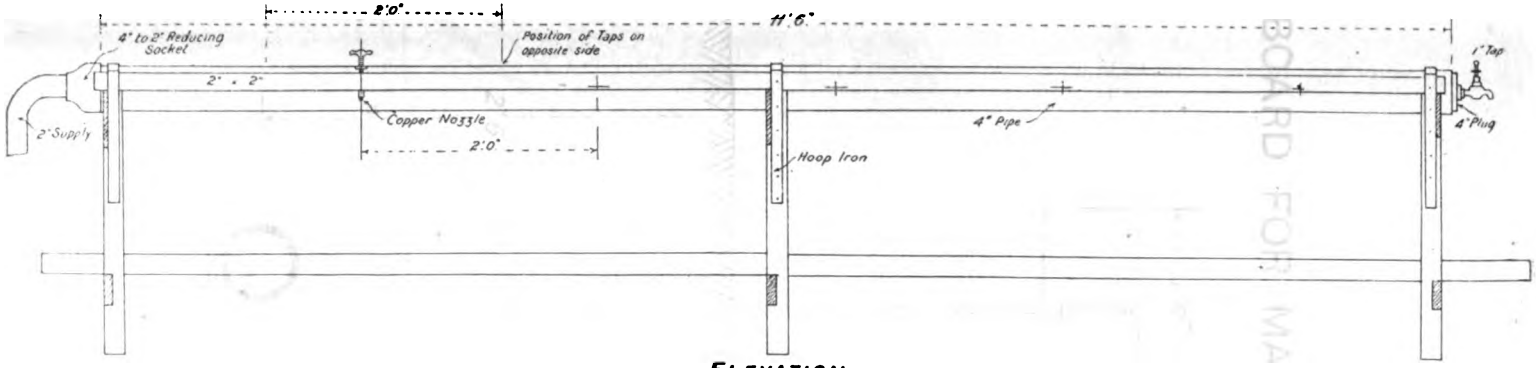
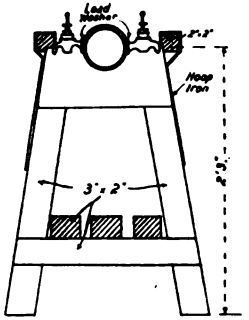
WATER BOTTLE FILLER.

FITTED WITH ¾-in. BRASS TAPS.



ELEVATION



SECTION

PLATE V.

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PLATE VI.

NOTICE BOARD FOR MARKING PIPE LINES.

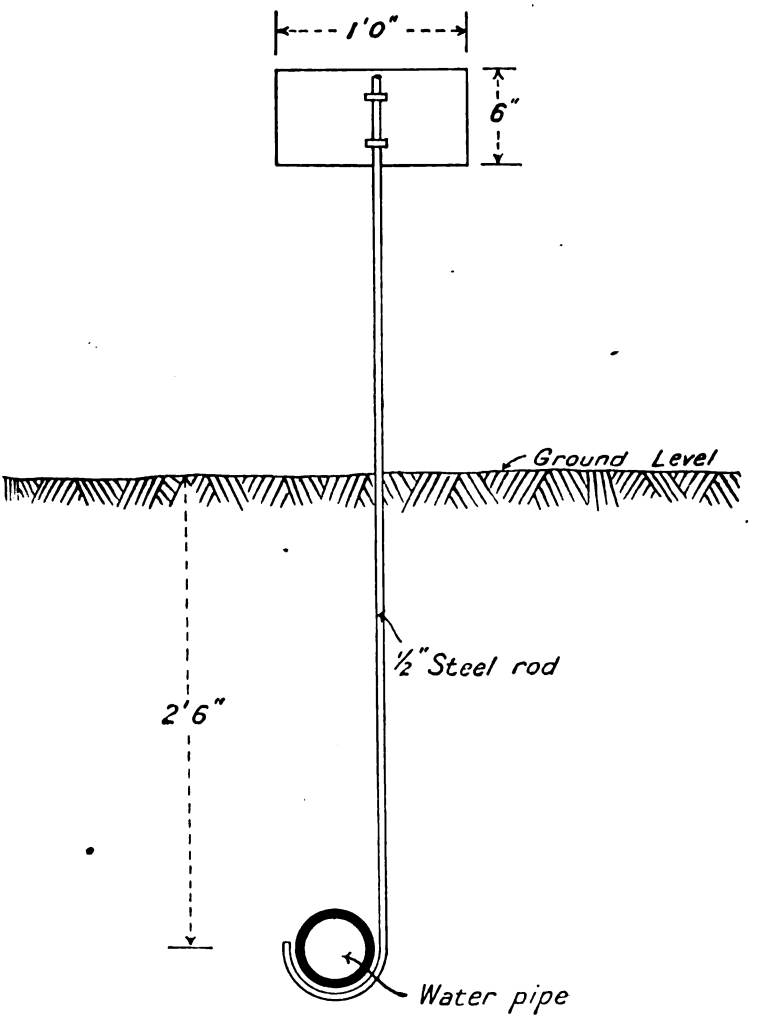

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PLATE VII.

WATER TANK.

WOOD, WIRE-MESH and CANVAS.

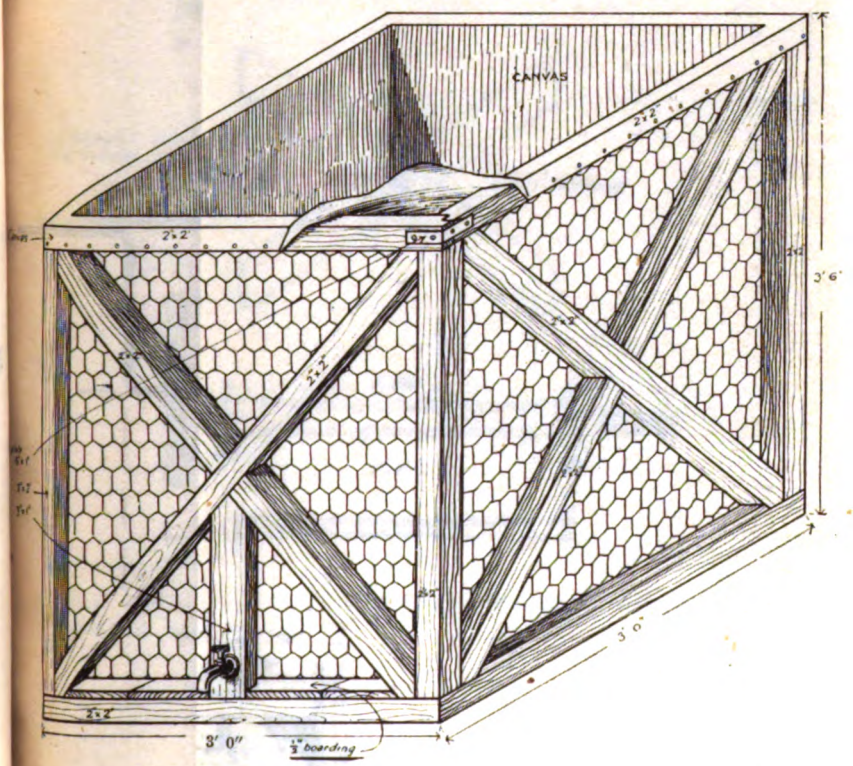

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PLATE VII.

WATER TANK.

WOOD, WIRE-MESH and CANVAS.

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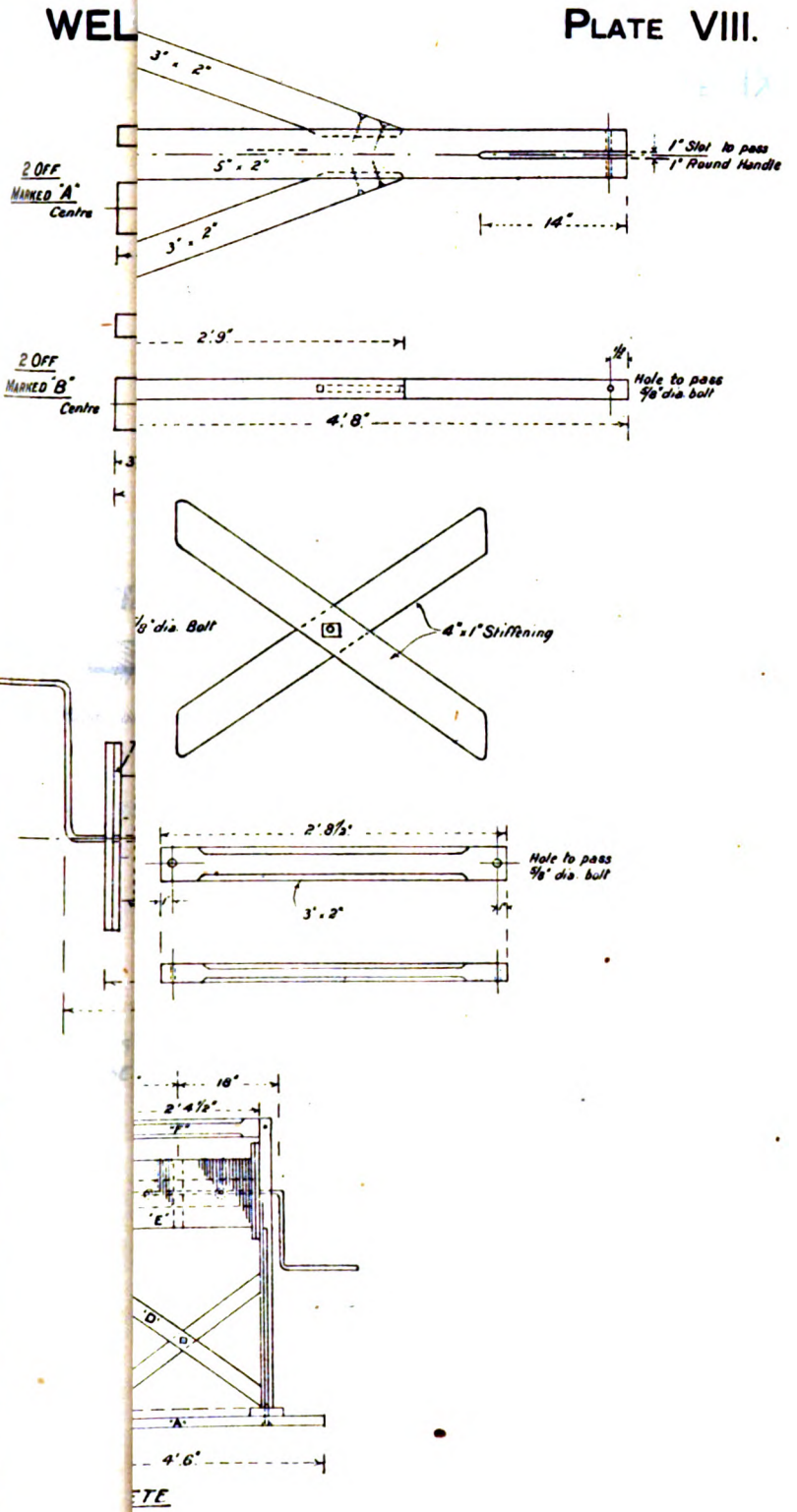
WEL

PLATE VIII.



ETE

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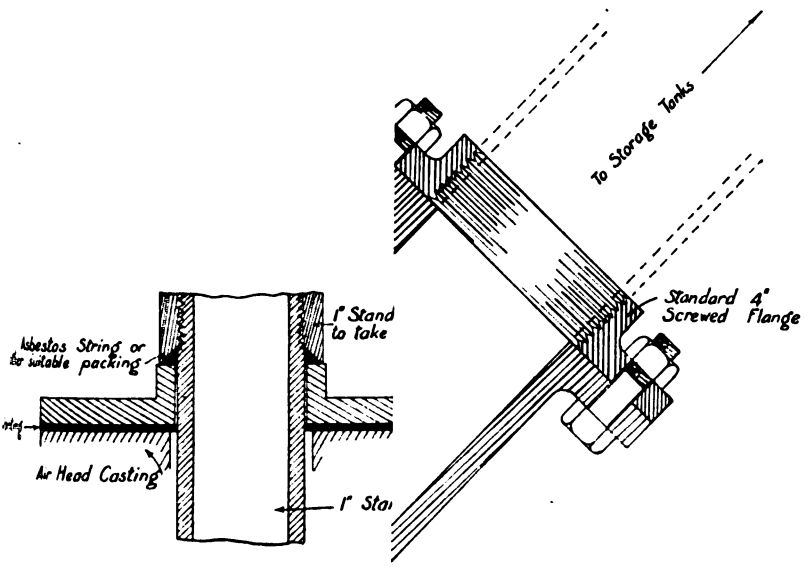
All

PLATE IX.

From Air Supply



sting supplied by R.E.S.O Havre

NOTE

ONLY PARTS SHEWN IN FULL LINE TO BE SUPPLIED

Thread

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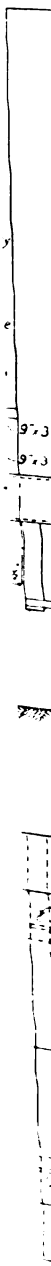

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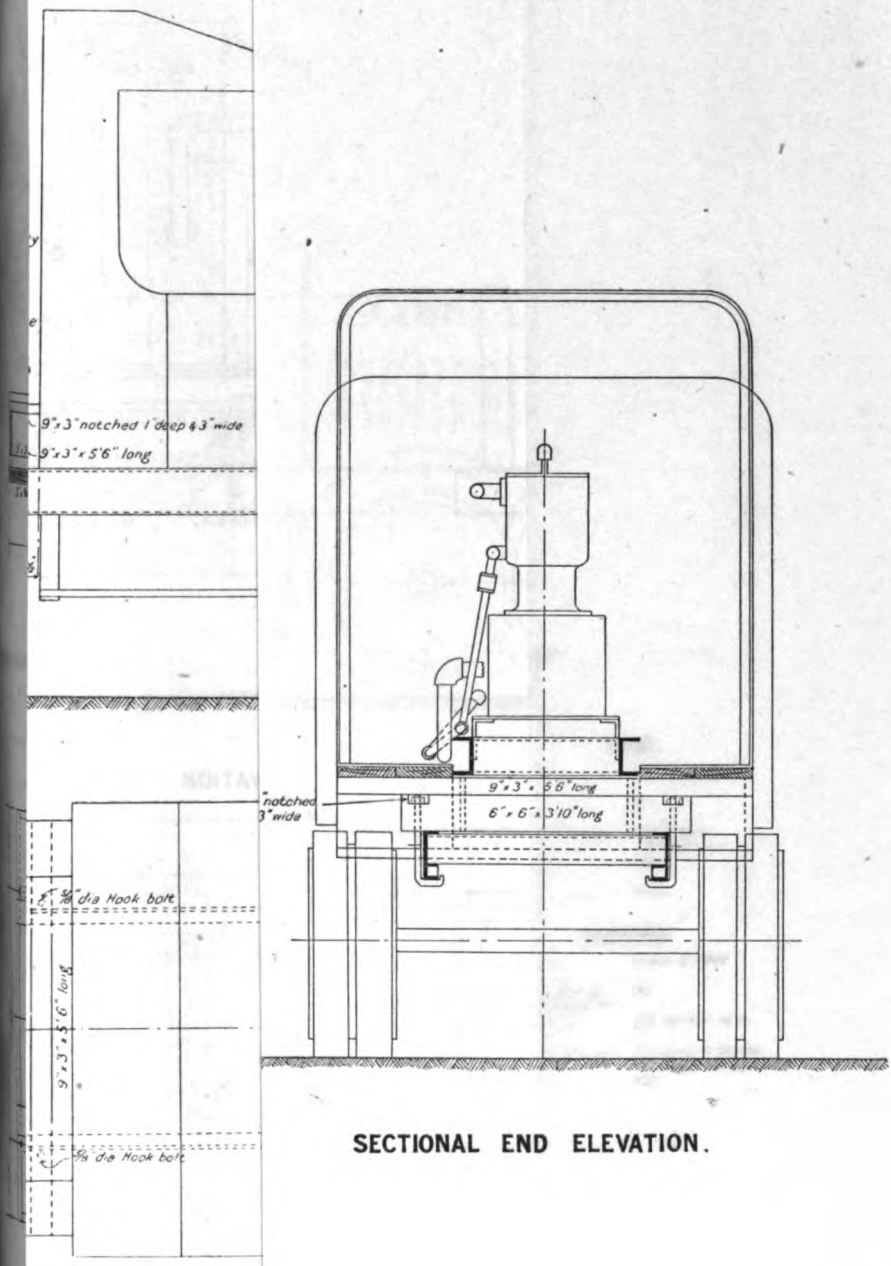
NTING AND

COMPRES-ORRY.

PLATE X.



SECTIONAL END ELEVATION.

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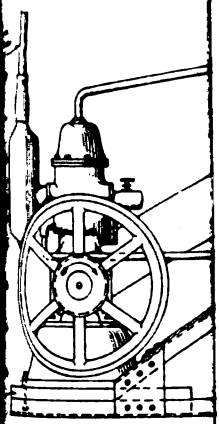
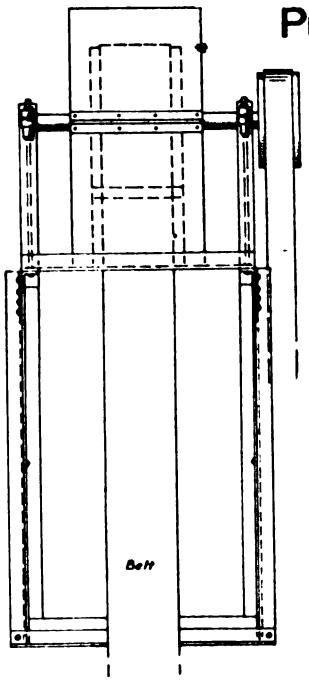
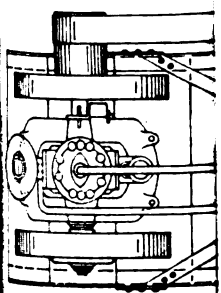
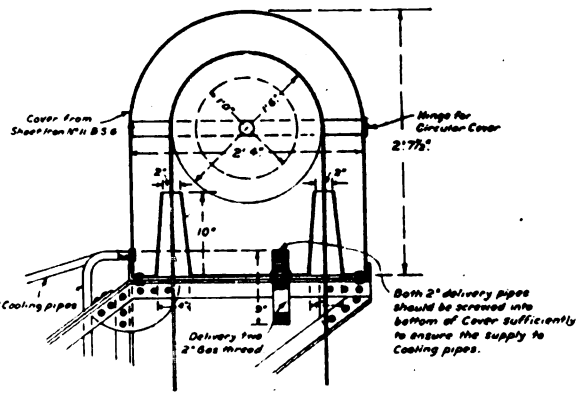
PLATE XII.



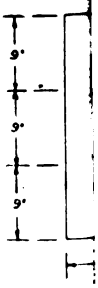


END ELEVATION.





SECTION THRO: BOX.



BELT PUMPING SET.

PLAN

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PLATE XII.

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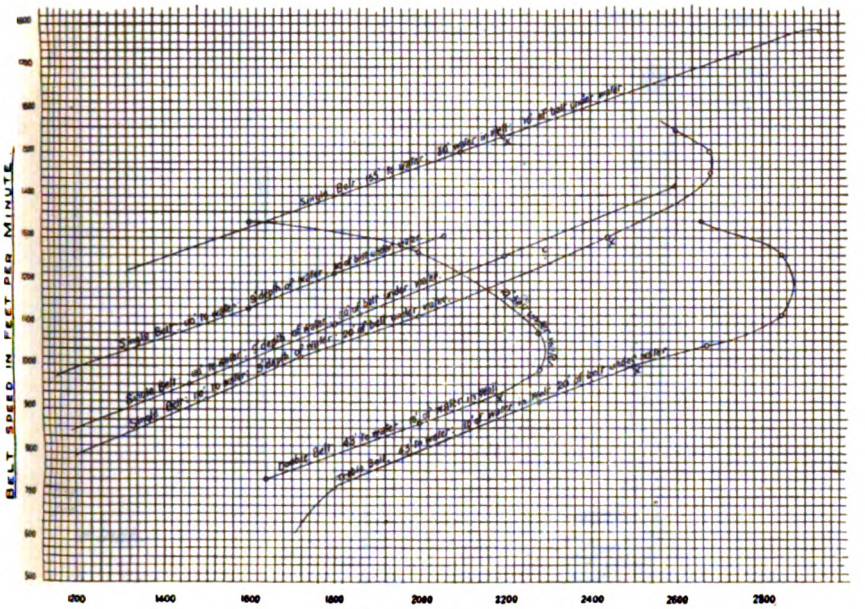
PLATE XIII.

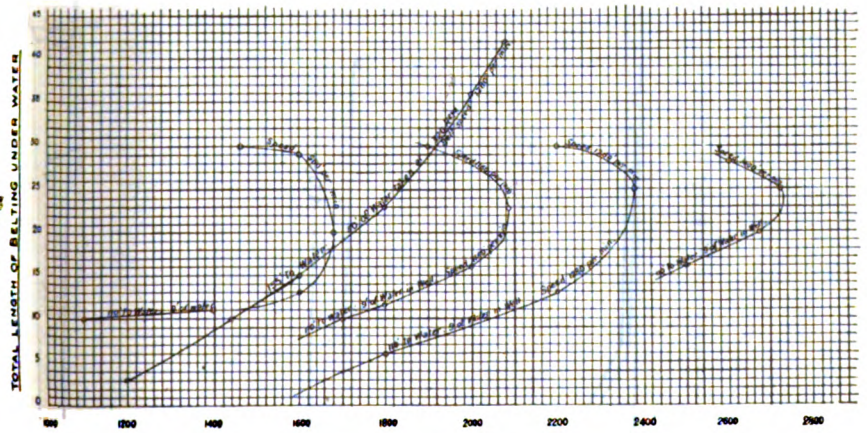
SPEED—OUTPUT CURVES IN WELLS OF VARYING DEPTHS AND IMMERSIONS.

Belt slipped at point X, after which tacks were inserted in the drum & a more powerful engine used. Belt slip begins at point X



IMMERSION—OUTPUT CURVES AT VARYING SPEEDS.

The conclusion drawn from these curves is that the most efficient working as regards Output is obtained when the total length of belt immersed is 6ft more than twice the lowest of water in the well. After this point any further lengthening of the belt results in the belt touching bottom when the pump is in action & a consequent falling off of output. In order to avoid any possibility of the belt touching the bottom of the well owing to stretching the following rule should be adopted:- Use a belt of such a length that its lowest point is six inches from the bottom of the Well when the belt is at rest



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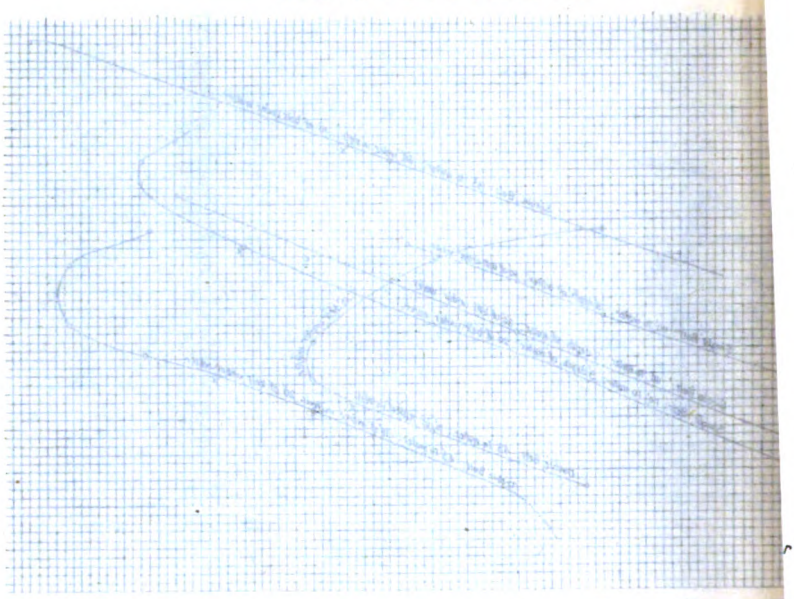


inch.

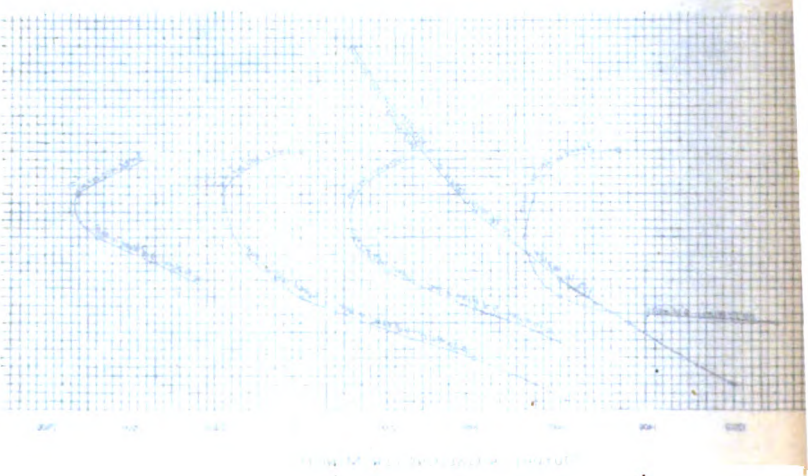
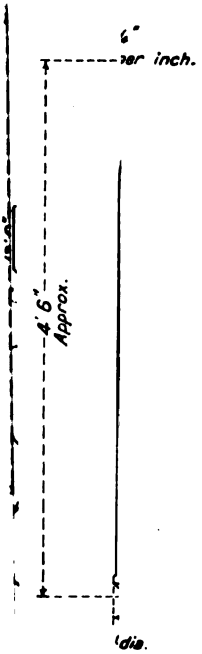
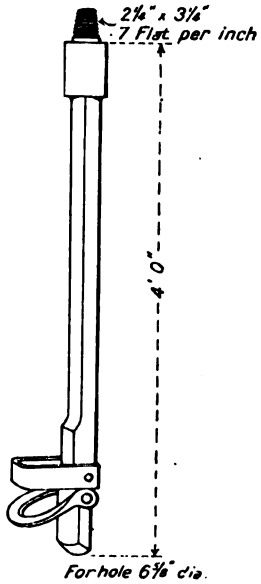


PLATE XIV.

FLUTE



HORSE-SHOE TRIP ROPE KNIFE WITH JARS

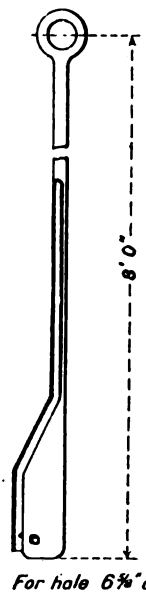


CA

R

SLIP

SOLID JAR BUMPER



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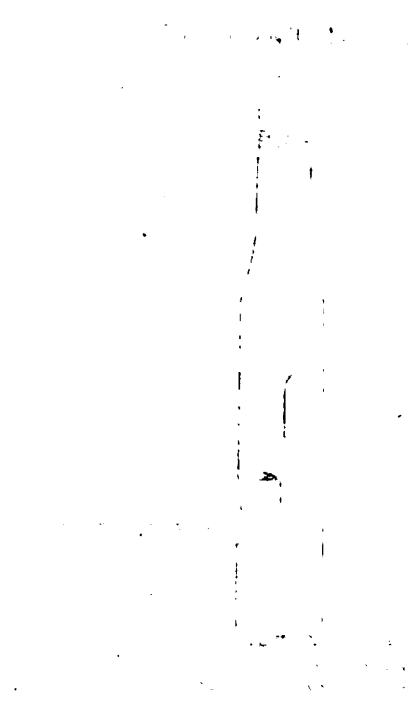

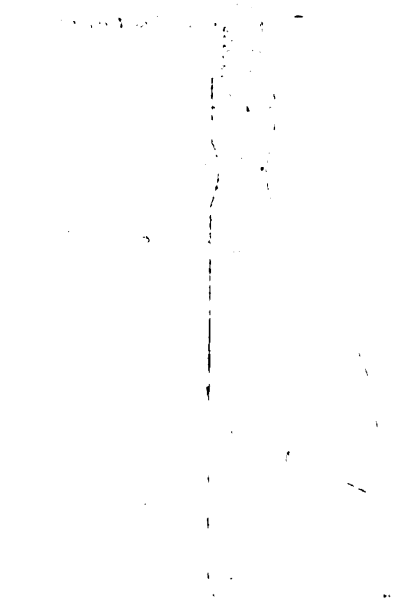

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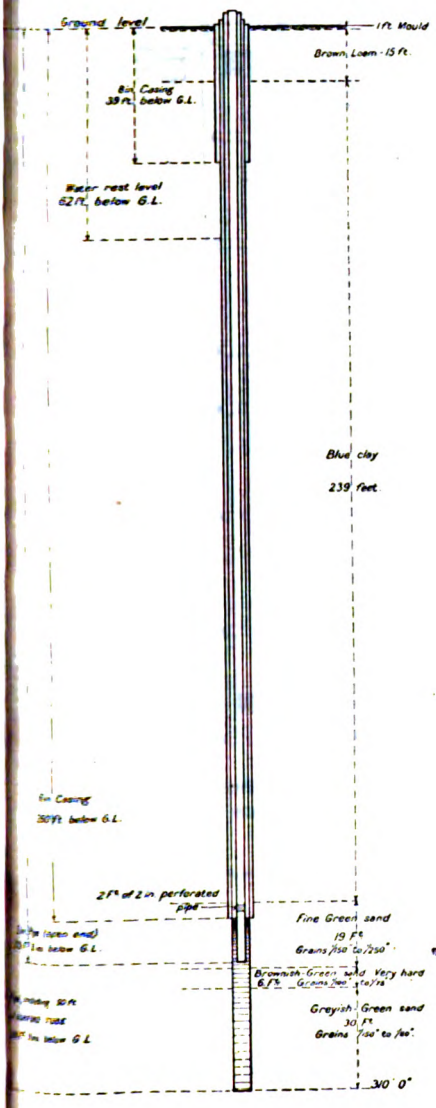
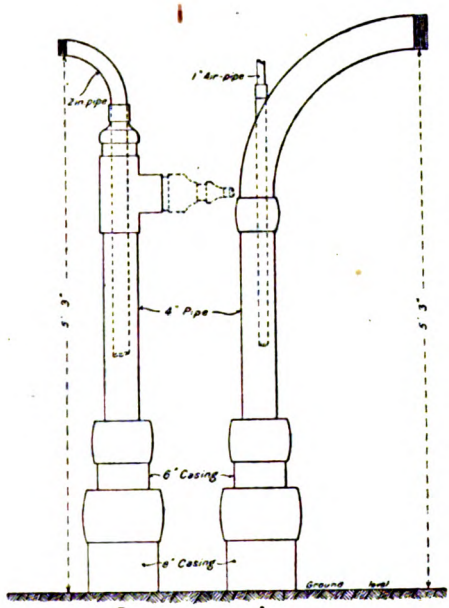
PLATE XV.

SECTION OF DEEP WELL BORE AT CUNEWELE.





SKETCH OF WELL-HEAD.

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PLATE XV.

SECTION OF DEEP WELL
BORE AT GUNNEWELL.

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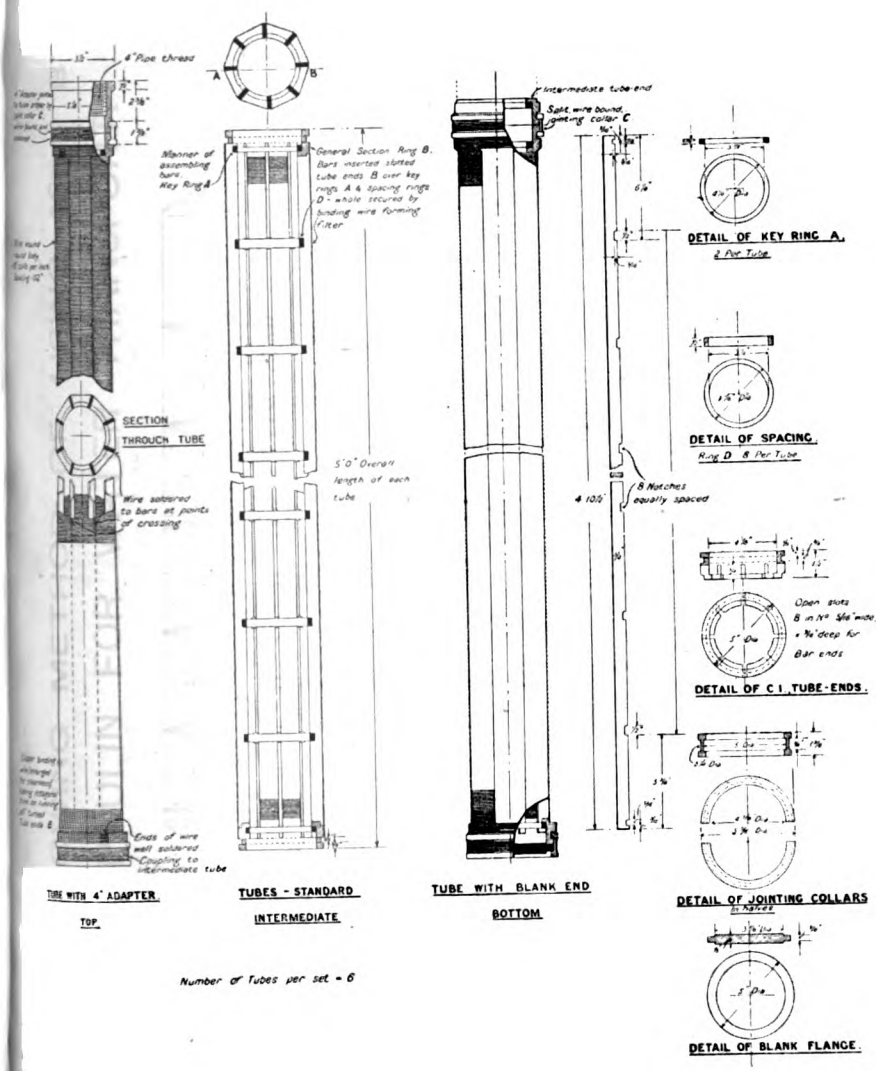
PLATE XVI.

ASHFORD FILTER TUBE.


4" Pipe thread
SECTION THROUGH TUBE
Wire soldered to bars at points of crossing
Ends of wire well soldered
Coupling to intermediate tube
TUBE WITH 4" ADAPTER TOP.
Manner of assembling bars. Key Ring A
General Section Ring B. Bars inserted slotted tube ends B over key rings A & spacing rings D - whole secured by binding wire forming filter
5'0" Overall length of each tube
TUBES - STANDARD INTERMEDIATE
Intermediate tube end
Split wire bound tightening collar C
8 Notches equally spaced
TUBE WITH BLANK END BOTTOM
DETAIL OF KEY RING A.
2 Per Tube
DETAIL OF SPACING Ring D 8 Per Tube
Open slots 8 in No 5/16" wide x 3/16" deep for Bar ends
DETAIL OF C.I. TUBE-ENDS.
DETAIL OF JOINTING COLLARS
DETAIL OF BLANK FLANGE.

Number of Tubes per set = 6

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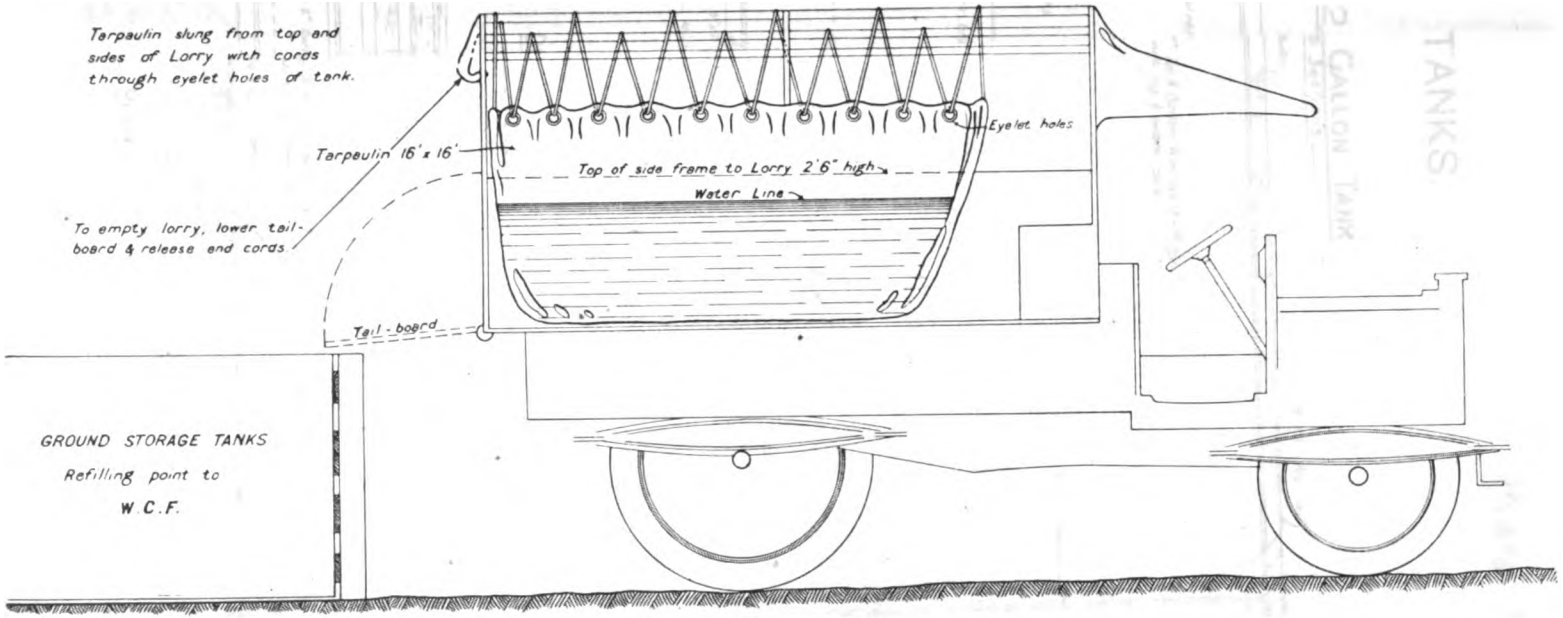
SKETCH SHOWING METHOD OF USING 16FT. BY 16FT. TARPAULIN FOR WATER TRANSPORT.


Tarpaulin slung from top and sides of Lorry with cords through eyelet holes of tank.
Tarpaulin 16' x 16'
To empty lorry, lower tail-board & release end cords
Eyelet holes
Top of side frame to Lorry 2'6" high
Water Line
Tail-board
GROUND STORAGE TANKS
Refilling point to
W.C.F.

SECTION THROUGH TARPAULIN ON LORRY.

PLATE XVII.

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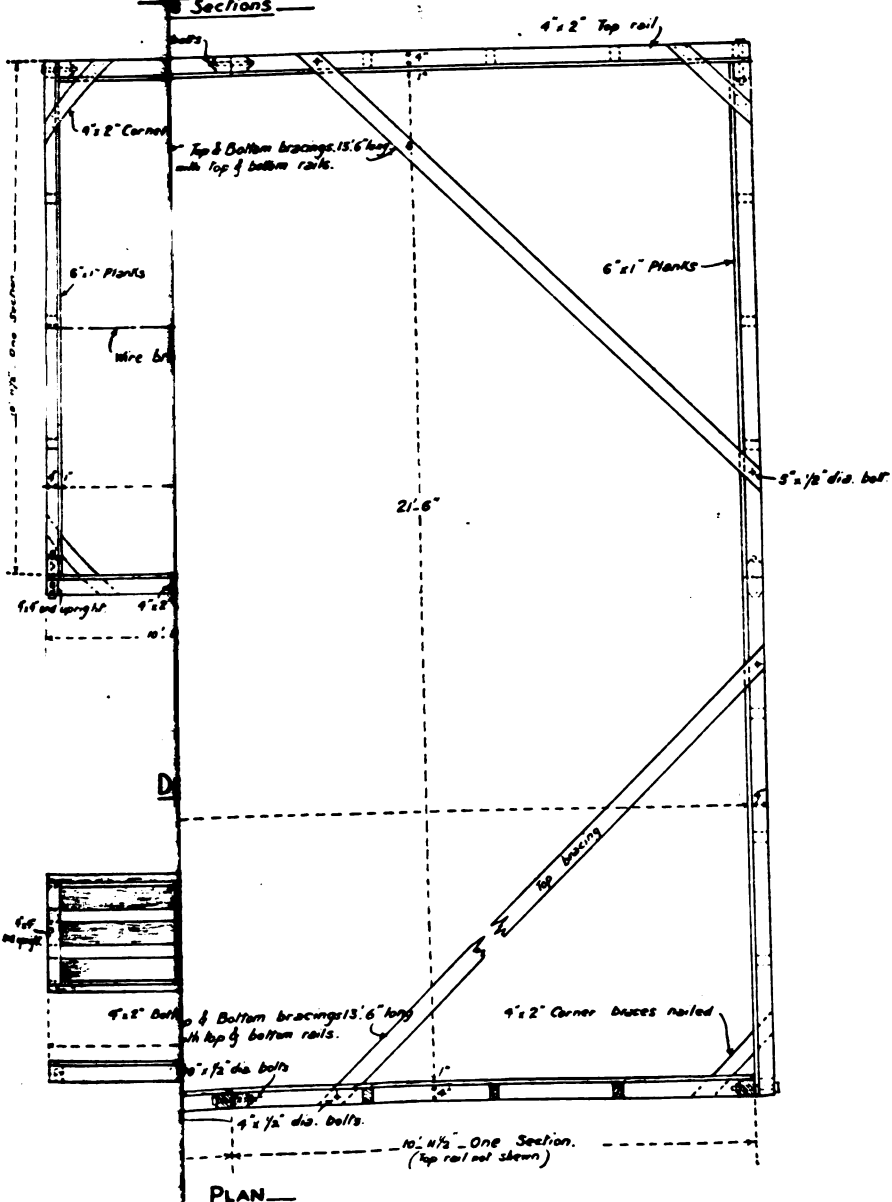
PLATE XVIII.

TANKS.

2 GALLON TANK

Sections


4"x 2" Top rail
Bolts
4"x 2" Corner
Top & Bottom bracings 15'6" long with top of bottom rails.
6"x 1" Planks
6"x 1" Planks
Wire br
5"x 1/2" dia. bolt
21'-6"
4"x 2"
Top bracing
4"x 2" Corner braces nailed
Top & Bottom bracings 15'6" long with top of bottom rails.
4"x 1/2" dia. bolts
4"x 1/2" dia. bolts
10'-11 1/2" One Section.
(top rail not shown)

PLAN

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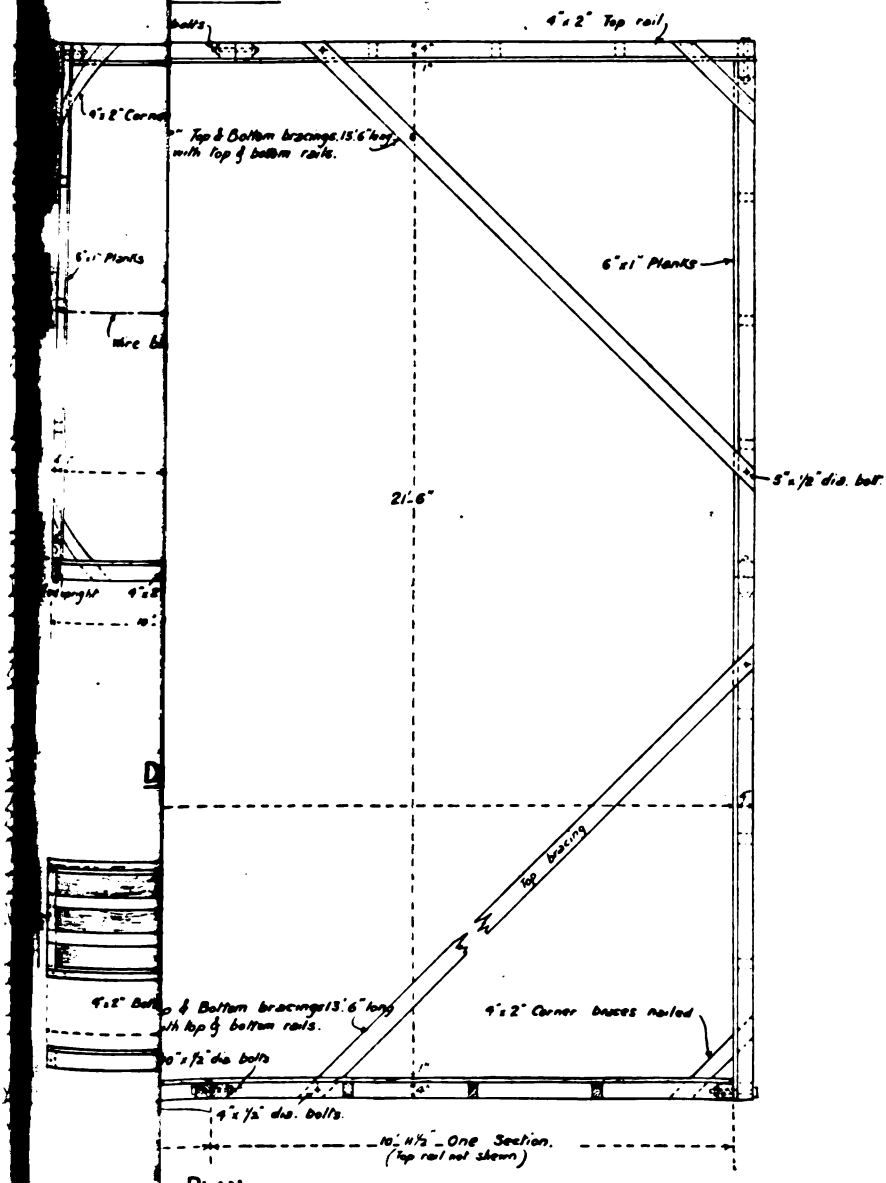
PLATE XVIII.

TANKS.

2 GALLON TANK

3 Sections



PLAN

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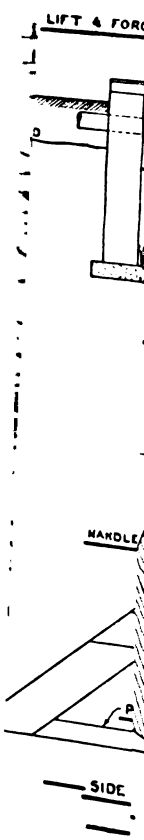

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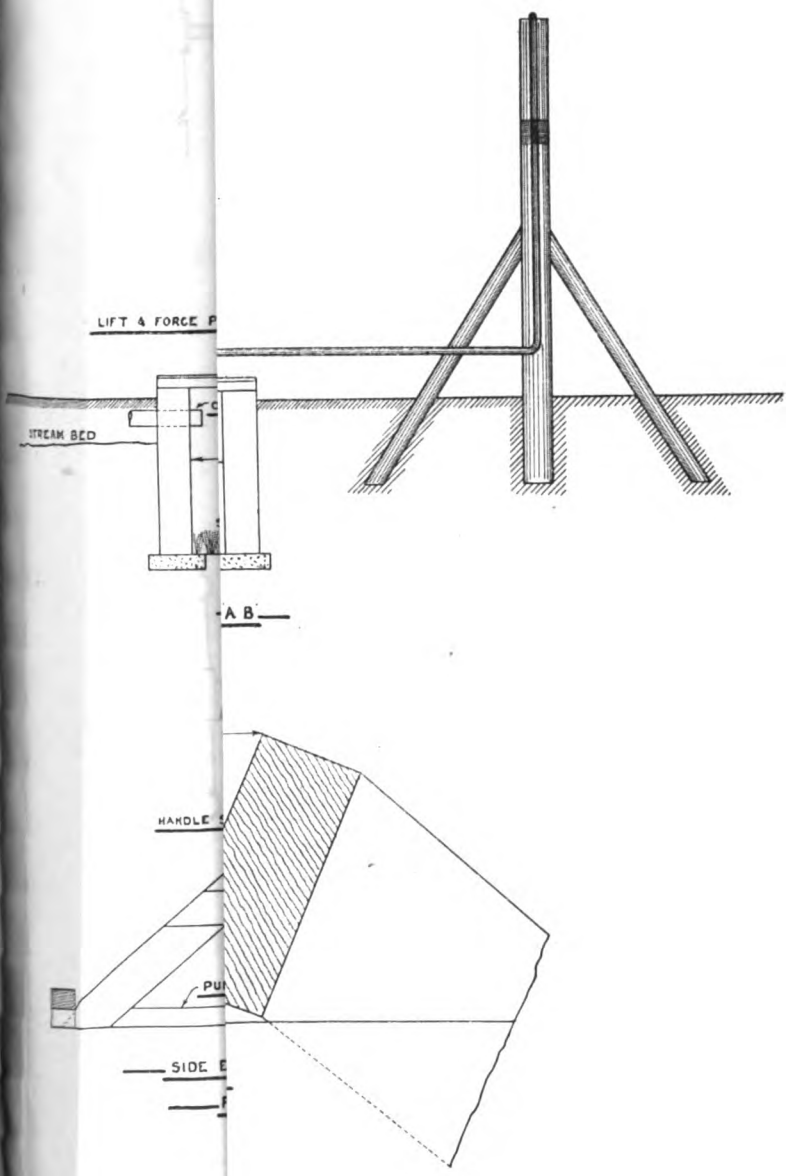
PLATE XXII.

ND



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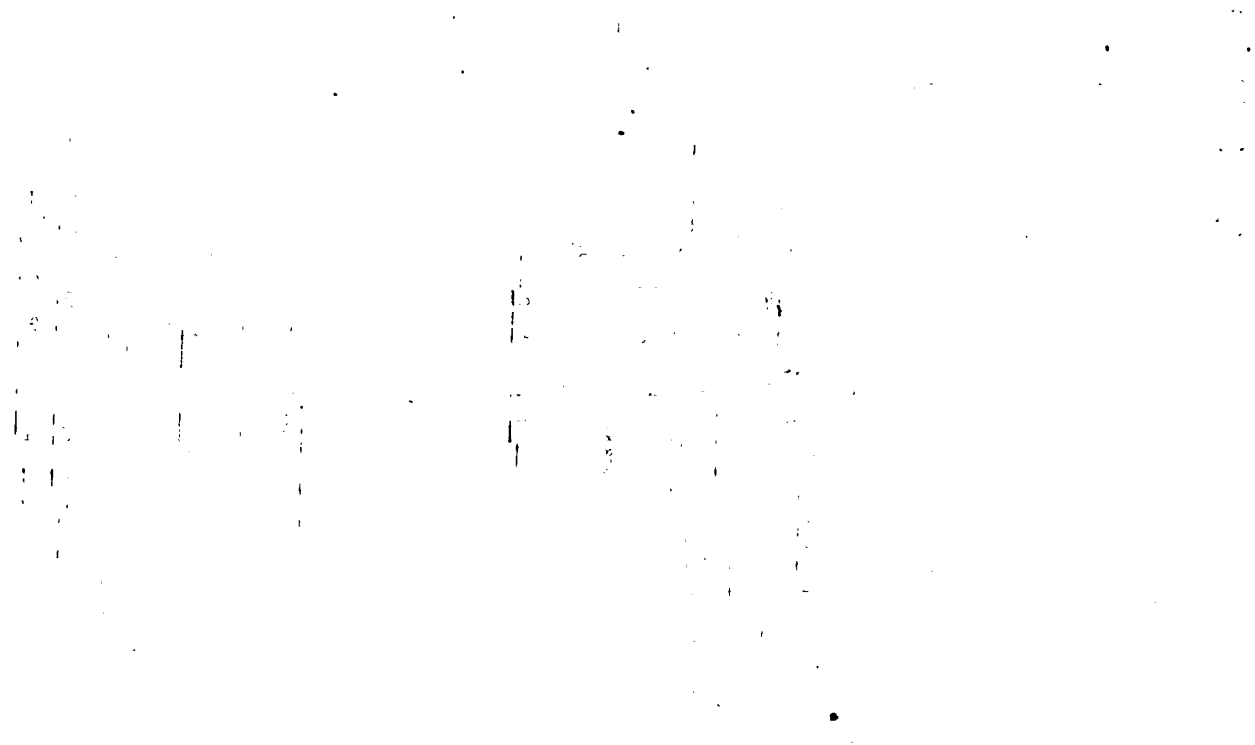
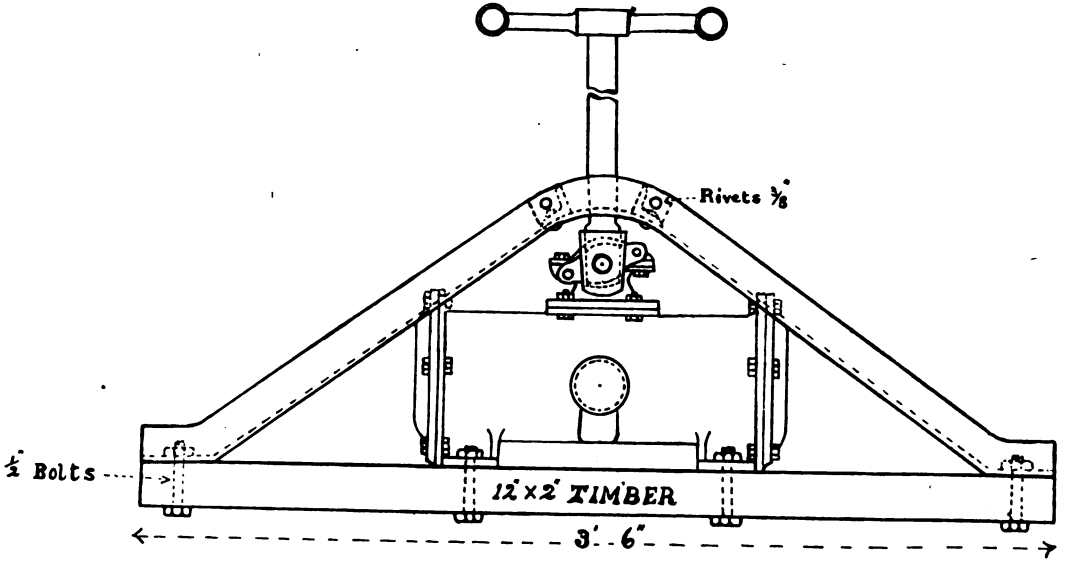


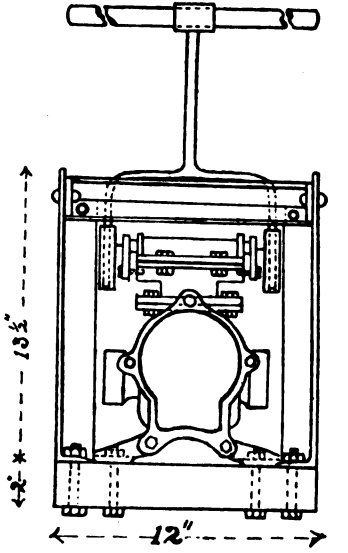
PUMP MADE FROM TWO LONG ANGLE IRON

PROTECTIVE FRAME.

FOR MARK IV. L & F PUMP, MADE FROM TWO LONG ANGLE IRON PICKETS.



SIDE VIEW



END VIEW

PLATE XXIII.

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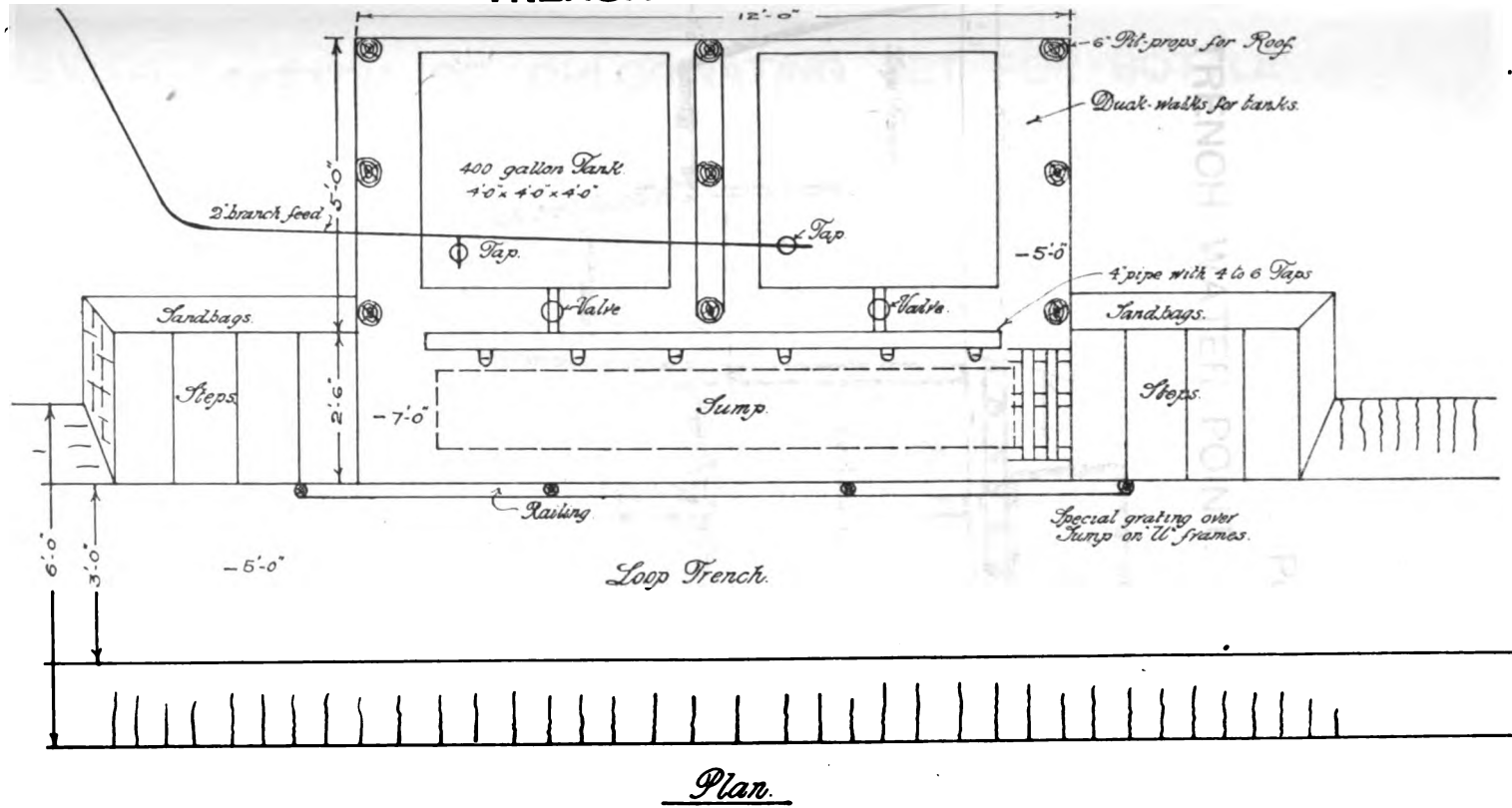
TRENCH WATER POINT.



Plan.

PLATE XXIV.

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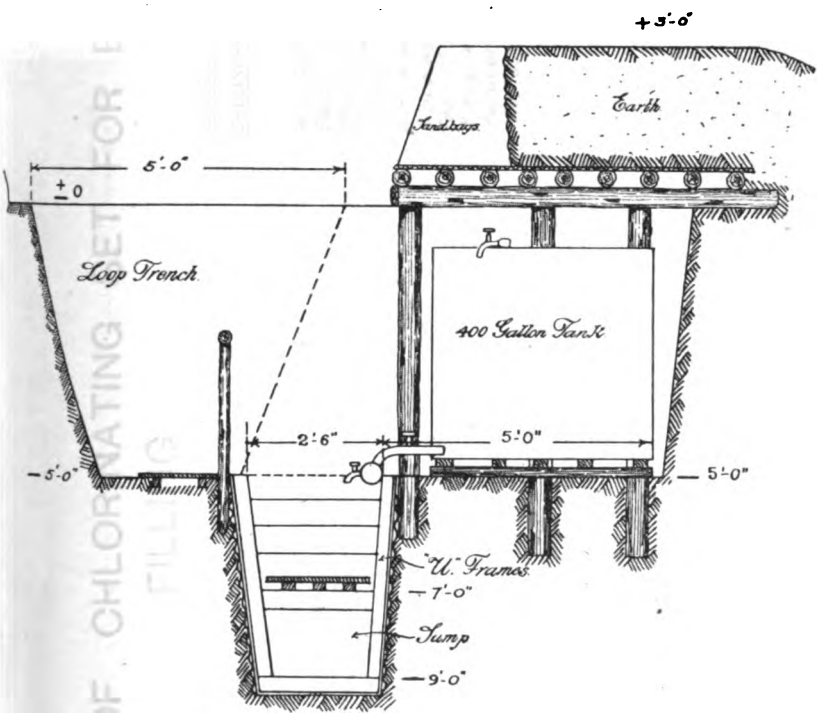
PLATE XXV.

TRENCH WATER POINT.



Section.

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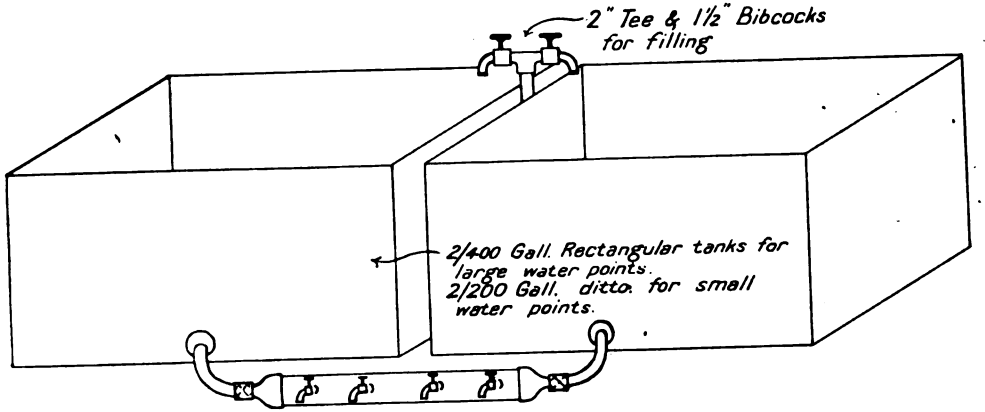
ROUGH SKETCH OF CHLORINATING SET FOR BOTTLE FILLING.



Tanks to be erected on wooden stands

STORES REQUIRED FOR WATER-POINT CHLORINATING SETS FOR BOTTLE FILLING.

400 Gall. Rectangular tanks	2
Bends, 1½"	2
Backnuts, 1½"	4
Stopcocks, 1½"	2
Sockets, 4" x 1½"	2
4" Pipe about 4'0" long	1
Bibcocks, ¾"	4
Tee, 2"	1
Bibcocks, 1½"	2
Reducers, 2" to 1½"	2
Nipples, 2"	2

PLATE XXVI.

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PLATE XXVII.

NON-AUTOMATIC "POSTE DE JAVELLISATION."

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EAU DE JAVEL AUTOMATIC SUPPLY.

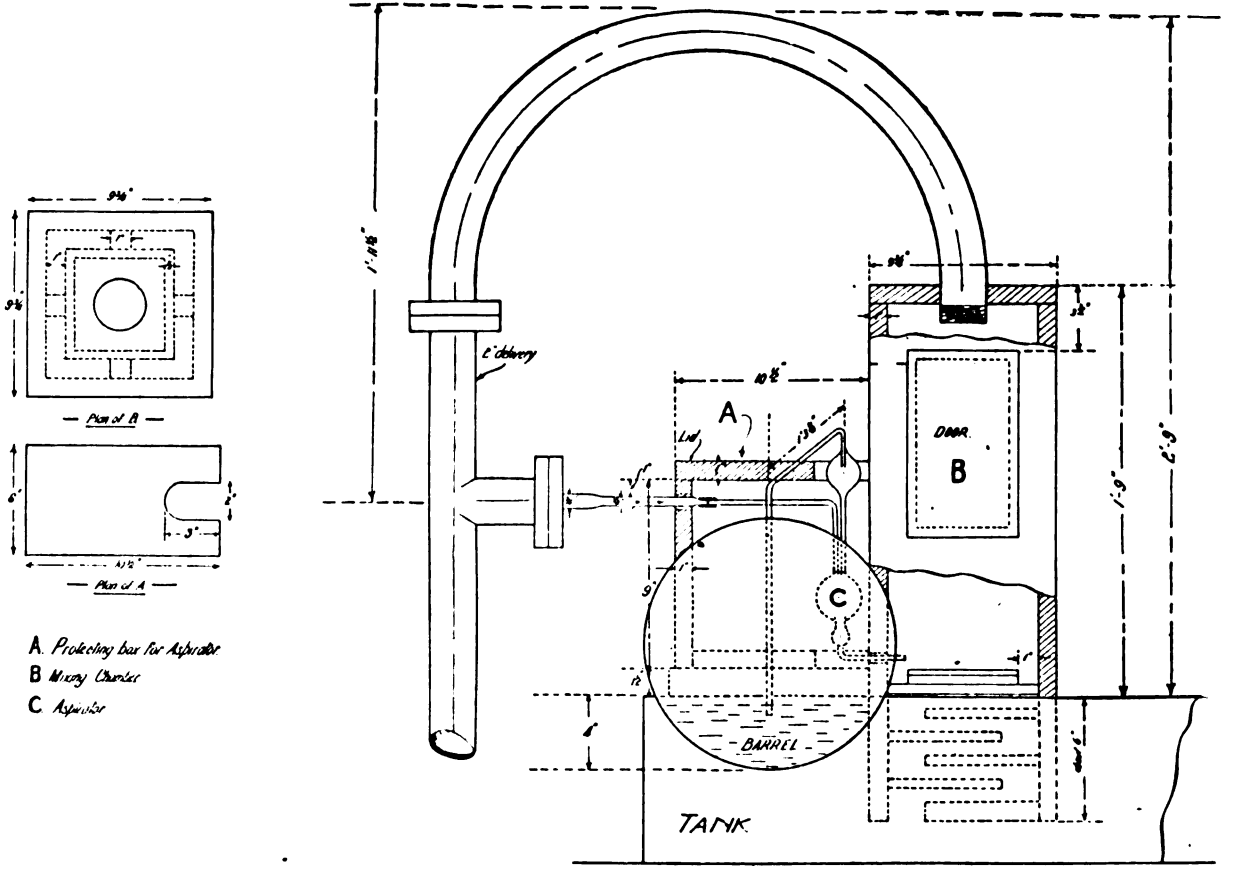

PLATE XXVIII.

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ADJUSTMENT TABLE
FOR USE WITH
ADJUSTABLE CONSTANT-FEED CHLORINATOR.

The Time (in seconds) to be taken for filling an 8-oz. Measure with Chloride of Lime Emulsion in order to chlorinate water in accordance with the following Table, which gives the quantity of water passing in gallons per hour, and the number of scoops-full required per water-cart.

Quantity of Water passing in Gallons per hour to be chlorinated.	Number of "Scoops-full per Water-cart" as shown by Preliminary Chlorination Test. (See instructions on Test Box).							
	½ Scoop-full per Water-cart.	1 Scoop-full per Water-cart.	1½ Scoops-full per Water-cart.	2 Scoops-full per Water-cart.	2½ Scoops-full per Water-cart.	3 Scoops-full per Water-cart.	3½ Scoops-full per Water-cart.	4 Scoops-full per Water-cart.
Gallons.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.
500	720	360	240	180	144	120	103	90
1000	360	180	120	90	72	60	51	45
1500	240	120	80	60	48	40	34	30
2000	180	90	60	45	36	30	26	22
2500	144	72	48	36	29	24	21	18
3000	120	60	40	30	24	20	17	15
3500	103	51	34	26	21	17	15	13
4000	90	45	30	22	18	15	13	11
4500	80	40	27	20	16	13	11	10
5000	72	36	24	18	14	12	10	9
5500	65	33	22	16	13	11	9	8
6000	60	30	20	15	12	10	8	7

The Standard Emulsion of Chloride of Lime always to be used with this apparatus is made as follows:—Eight gallons of water to be added to the contents of a 4-oz. tin of Chloride of Lime (or Bleaching Powder).

N.B.—(i.) The usual careful method of preparing the emulsion is to be employed. First of all make the usual thick paste which is gradually to be thinned down.

(ii.) Use only freshly-opened tins of Chloride of Lime.

PLATE XXIX.

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Table of quantities of Emulsion required for "One Hour's Feed."

N.B.—Never make up more Emulsion at one time than is required for "12 hours' feed."

	½ Scoop-full per Water-cart.	1 Scoop-full per Water-cart.	1½ Scoops-full per Water-cart.	2 Scoops-full per Water-cart.	2½ Scoops-full per Water-cart.	3 Scoops-full per Water-cart.	3½ Scoops-full per Water-cart.	4 Scoops-full per Water-cart.
	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
500 gallons ...	¼	½	¾	1	1¼	1½	1¾	2
1000 ,, ...	½	1	1½	2	2½	3	3½	4
1500 ,, ...	¾	1½	2¼	3	3¾	4½	5¼	6
2000 ,, ...	1	2	3	4	5	6	7	8
2500 ,, ...	1¼	2½	3¾	5	6¼	7½	8¾	10
3000 ,, ...	1½	3	4½	6	7½	9	10½	12
3500 ,, ...	1¾	3½	5¼	7	8¾	10½	12¼	14
4000 ,, ...	2	4	6	8	10	12	14	16
4500 ,, ...	2¼	4½	6¾	9	11¼	13½	15¾	18
5000 ,, ...	2½	5	7½	10	12½	15	17½	20
5500 ,, ...	2¾	5½	8¼	11	13¾	16½	19¼	22
6000 ,, ...	3	6	9	12	15	18	21	24

The standard Emulsion of Chloride of Lime always to be used with this apparatus is made as follows:—Eight gallons of water to be added to the usual 4-oz. tin of Chloride of Lime (or Bleaching Powder).

N.B.—(i.) The usual careful method of preparing the emulsion is to be employed. First of all make the usual thick paste, which is gradually to be thinned down.

(ii.) Use only fresh-opened tins of Chloride of Lime.

PLATE XXIXA.

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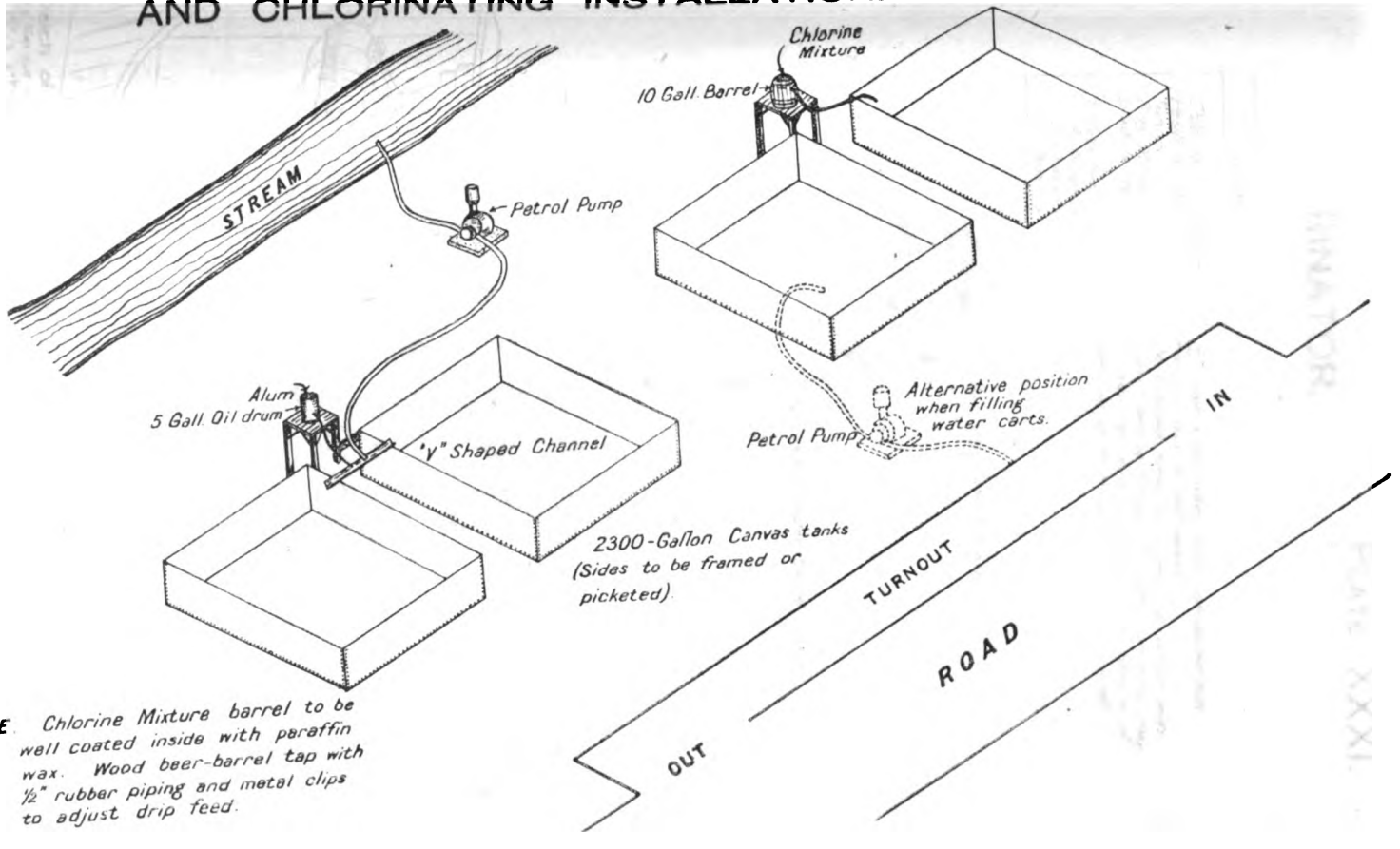
DIAGRAM SHOWING PORTABLE ALUM SEDIMENTATION AND CHLORINATING INSTALLATION.



NOTE. Chlorine Mixture barrel to be well coated inside with paraffin wax. Wood beer-barrel tap with ½" rubber piping and metal clips to adjust drip feed.

PLATE XXX.

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ADJUSTABLE

ACCESSORIES
Chlorination Testing Set Pestle & Mortar Funnel 8 oz. Measure Graduated Rod. to measure emulsion in barrel Tablets (limits 300 to 6000 gals per hour) A. Gauge of flow thro V notch B. Quantity of emulsion required C. Feed adjustment (emulsion)

Consult Table B for quantity required per hour } Graduated Rod to measure emulsion in barrel

See Table C } screw regulating Pinch cock

Funnel at base of Tab covered with cotton gauze

Regulating Valve

Glass Tube for hinge

Valve Rubber tipped

Cork Float

Unchlorinated

Sketch of Box.
(Lid & Top cut away showing valve & Float.)

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PLATE XXXI.

RINATOR.

ACCE:

Chlorination NOTE.
Pestle & Mo
Funnel
8 oz. Measur
Graduated J.

Tablets (limits
A Gauge o
B Quantity
C Food co

All wood & cork which comes into contact with emulsion must be well waxed
No exposed metal parts come into contact with Liquid passing through this apparatus which may therefore be similarly employed with solutions of Sulphate of Alumina, emulsions of Lime etc.

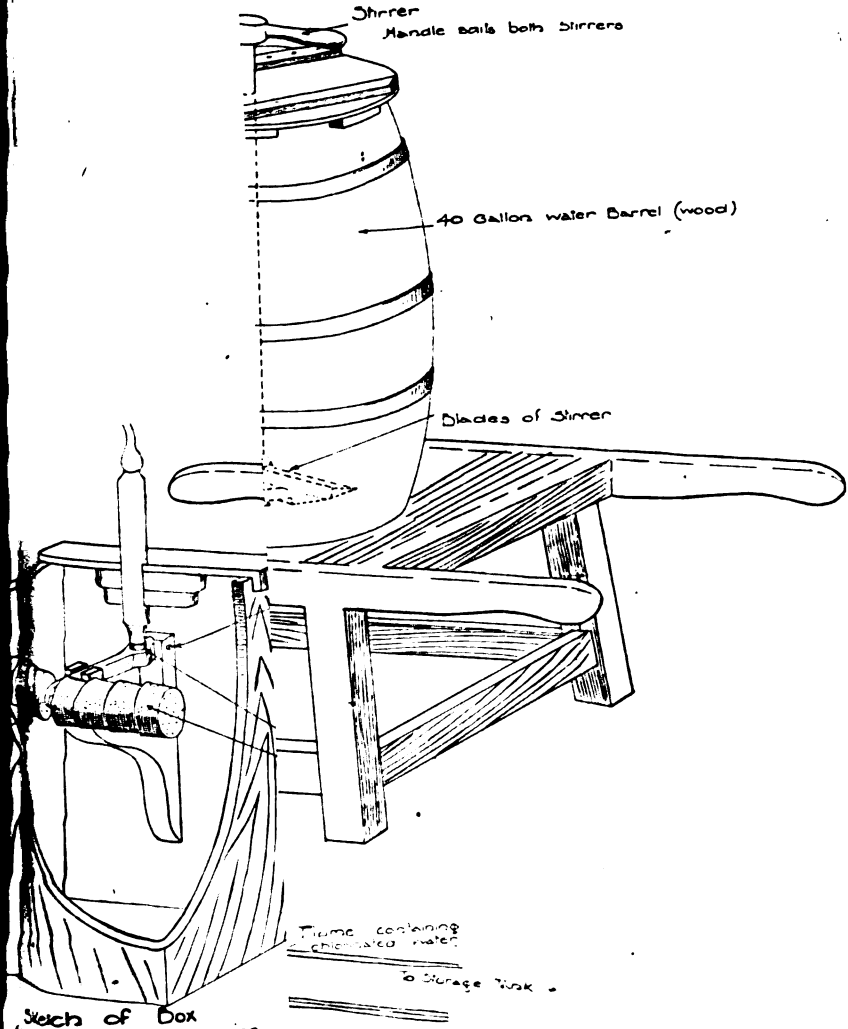

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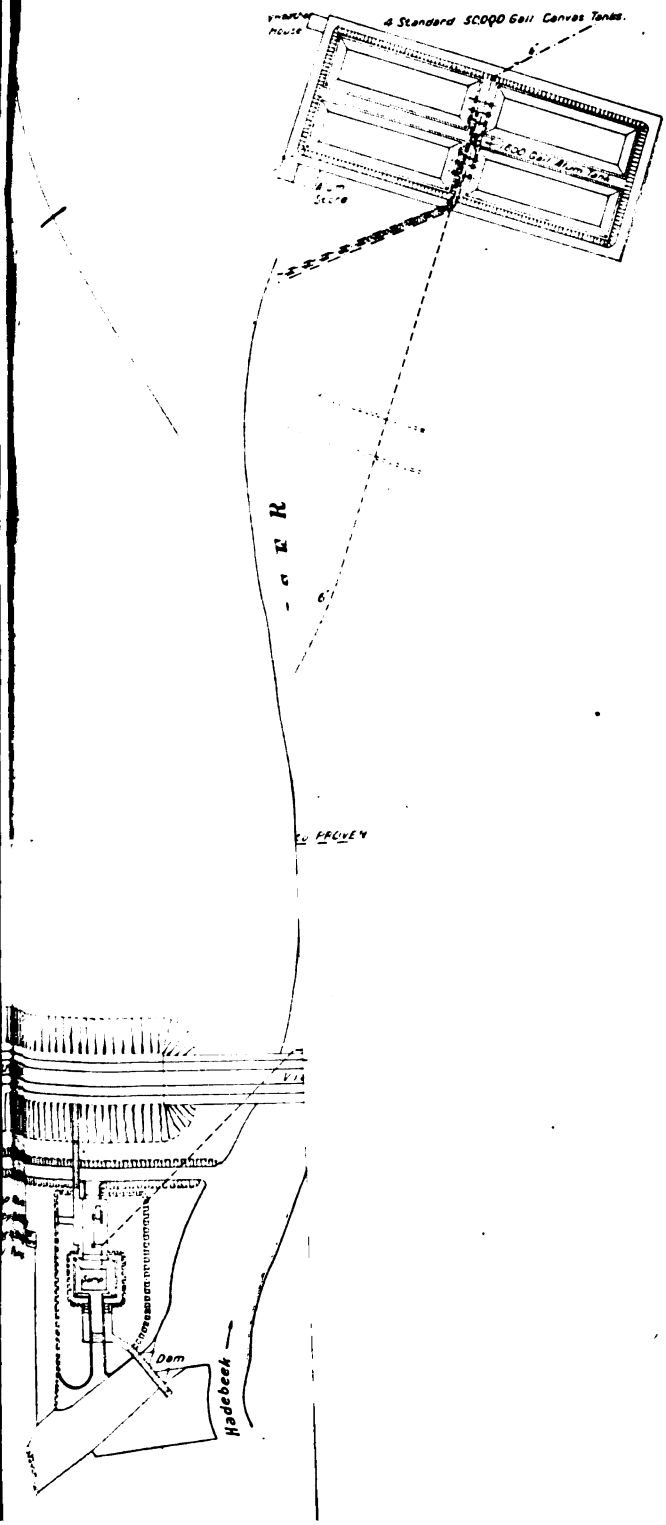
PLATE XXXII



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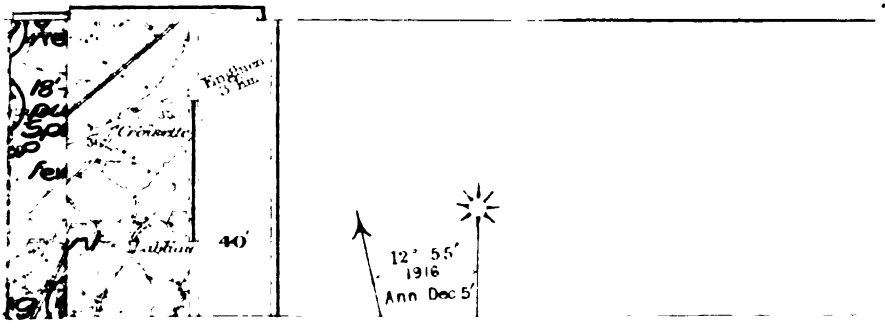

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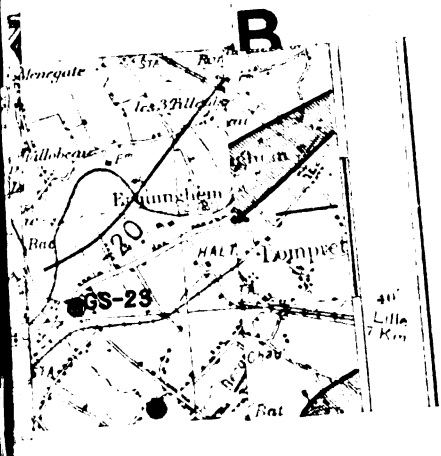

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PART II.

OPERATIONS.

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Chapter I.

THE SOMME, 1916.

1. *Preparatory Measures.*—At the end of the year 1915 the Third Army was holding a long front in the Somme area.

Towards the end of this year orders had been received to prepare for a concentration of troops on a far bigger scale than any previously experienced. The administrative Water Supply developments that resulted have already been briefly described in Part I. (Chapter 1, paras. 7, 8 and 9.)

In March, 1916, the Fourth British Army took over from the Third Army the front from the River Somme on the south to the Gommecourt salient, about 10 miles south of Arras, and at the same time orders were issued that work was not to be confined to preparations for a large concentration only, but was to include all the necessary arrangements for a general advance. Such an advance would take the Army across a practically waterless plateau, and the organization for supplying troops and horses with water during the advance at once assumed great importance. The arrangements that were made were fully described in a "Memorandum on Advanced Water Supplies, Fourth Army," issued in June. The general scheme of this memorandum was copied by practically every British army engaged in subsequent and similar operations, and will therefore be described in some detail. It opens with a general summary of the development up to date, including copious extracts from the reports of the Water Supply Committee (see Part I., Chapter 1); it then gives an outline of the hydrographical conditions of the area on the immediate front of the Army.

The remainder of the Memorandum will be quoted in full:—

Advance Supply Schemes.

10. *Preparations are being made on the following lines (see Index Map and Tabular Statements annexed):—*

(*a*) *Trench Supplies.—The water supplies to the forward trenches are being developed so that as large a supply as possible may be available during the early stages of an advance and in order to reduce the wheeled transport to a minimum.*

Vessels for distributing water by hand to the troops are also being provided.

(*b*) *Initial Water Points.—Initial water points have been established where posssible in the forward area for rapidly filling water-carts and water lorries by overhead hose. (See Table A. and Index Map).*

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Table A.

INITIAL WATER POINTS.

No.	Map Reference.	Corps.	No. of Taps for filling.	Storage. Gallons
1	J.17.c	VIII.	6	7,200
2	J.29.b.	VIII.	—	18,000
3	Q.1.a.	VIII.	6	8,800
4	Q.7.a.	VIII.	4	8,000
5	Q.7.c.	VIII.	4	8,000
6	Q.34.a.	X.	10	—
7	W.5.a.	X.	10	14,000
8	W.11.d.	X.	9	8,000
9	E.4.a.	III.	6	8,000
10	E.4.b.	III.	6	8,000
11	E.26.c.	XV.	6	8,000
12	K.8.a.	XV.	10	30,000

(*c*) *Advance Water Supplies.—Advance pumping stations have been installed and pipe lines laid through the trenches as far as practicable, and measures taken to continue these lines forward on to and, if necessary, across the high ground to our front, and establish a series of forward water points thereon for filling water transport.* (*See Table B. and Index Map*)

Table B.

ADVANCE PUMPING STATIONS.

No.	Map Reference.	Corps.	Pumps.	First Objective for Pipe Line.
A.	J.16.b.	VIII.	2,700 g.p.h. against 450′	Reinforces "C" Installation.
B.	K.15.b.	VIII.	2,700 g.p.h. against 450′	As on Index Map.
C.	K.33.c.	VIII.	1,000 g.p.h.	As on Index Map.
D.	Q.30.b.	X.	2,400 g.p.h. against 350′	Crucifix N.E. of Thiepval.
E.	W.12.a.	X.	4,000 g.p.h. against 450′	Farm du Mouquet.
F.	W.11.b.	III.		Cemetery, Pozières.
G.	E.4.d.	III.	4,000 g.p.h. against 450′	N. of Contalmaison.
H.	E.16.d.	XV.	7,000 g.p.h. against 250′	Reinforces "I."
I.	F.8.a.	XV.	2,600 g.p.h. against 350′	Rose Cottage on E. of Fricourt.
J.	G.8.c.	XIII.	5,000 g.p.h. against 250′	N. of Briqueterie.
Barge Unit—				

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(d) Mobile Pumping Sets.—The provision at a central depôt of a limited number of deep-well pumps and pumping sets of considerable power on wheels for use at suitable places in advance.

(e) Water Barges.—The provision of two water barge units on the River Somme, each unit capable of delivering 4,000 gallons of filtered potable water per hour, and provided with pumps for forcing water through pipes laid inland.

(f) Additional Water Carts.—The establishment of regimental water carts is being augmented by the addition of 80 water carts per corps.

(g) Army Water Columns.—A Water Tank Company and a number of 3-ton lorries fitted with tanks, as described in Part II. (Page 62), have been allotted to the Army for working between the initial and forward water points and the divisional water carts.

11. *During the early stages of an advance (trench fighting) troops would depend on the trench supplies (a) and their water-carts, the latter filling as at present or from the initial water points (b). It is unlikely that the water columns would be able, or be required, to work until practicable roads are pushed through the trenched area, or that conditions would permit of their use until the German first system of defence is cleared.*

The advance pipe lines (c) would be pushed forward as circumstances permit from the pumping stations that survive the bombardment, and could possibly supplement the supplies during this stage by small branches and taps, but in doing this the greatest care should be taken not to jeopardize the main object of the advance lines (i.e., the establishing of forward water points on the high ground) by expending pipe fittings and specials unnecessarily, the numbers of which are limited, and the difficulties of replenishing stock are increasing.

12. *When the advance extends beyond the range of the water-carts working from sources within our present area, and roads are practicable for working the water columns (g), the latter would commence carrying from the initial water points to refilling points behind the troops.*

The extreme range of the water columns would be about 10 miles, to which say three miles for the water-carts can be added, but a total carry from source to troops of 13 miles could only be maintained for a short time on emergency, and with roads congested with traffic probably not more than half this distance could be averaged.

Before the above extreme range is reached it should be possible to establish at least some of the forward water points on the high ground beyond the German lines, and the water columns would then work from these points instead of returning to the initial water points. Also, as opportunity offers, the mobile pumping sets (d) would be sent forward to sources of supply and establish additional water points from which the water columns or water-carts could work.

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13. *It must be expected that a number of the pumping stations will not survive the bombardment, and that the pipe lines in the shell area will be greatly damaged and cut, and require time to repair.*

Also that traffic conditions will render the working of the water columns most difficult.

The pumps installed can deliver large quantities of water (2,000 *to* 5,000 *gallons per hour and over*) *through long lengths of pipe and to the top of the plateaux, but the amount of water which can be delivered to the troops will depend on the carrying capacity of the water transport, and on its being available to fill from the tanks at the forward water points before water runs to waste at their overflow.*

14. *The arrangements that have been made for the adequate and regular distribution of water to the troops from the advance supplies are therefore dependent on a great number of uncertain factors, and it is essential that they should be treated as only supplementary to the development of the local sources of supply.*

Corps must, therefore, take steps to develop the local supplies from wells and streams under the usual divisional arrangements, and the above arrangements made by the Army do not lessen the responsibility of formations regarding their water arrangements.

15. *A list of wells in the area in question is also issued and a study of it, the contoured maps, and para. 7 above, will be a guide as to where water may be expected, and the estimated depths at which it is may be found.*

16. *The French have organized detachments of well sinkers for rapidly sinking numbers of wells in valleys close behind advancing troops in country similar to that in our front, and it is understood that this has been of great assistance.*

It seems probable that water might be quickly found and developed in this manner (*especially in the valley district, see para. 7*) *within reach of ordinary suction* (*up to 25 ft. depth*), *and the powerful pumps on wheels* (*L.C.C. engines, etc.*), *could be sent to such points and pump from them to the high ground.*

17. *The preparations* (*a*), (*b*), (*c*) *and* (*d*), *para.* 10, *are Engineer Services and are being carried out by corps.*

The water barges (*e*) *have been allotted to the corps on the right of the Army, and the permission of the French has been obtained to move them forward by the Somme Canal in order to pump water inland if this is required.*

18. *The initial water points call for no detailed description. They will be in charge of the corps in which they are situated.*

19. *The Advance Water Supply lines are being carried out by R.E. units specifically allotted for the purpose, and the delivery of the water into the tanks at the forward water points will be a R.E. service.*

The filling of the water transport from the tanks at the forward water point and its distribution to the troops will be a supply service.

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20. *The R.E. unit will carry the equipment for forming the forward water points, consisting of eight waterproof canvas tanks (each 2,000 gallons capacity), four petrol pumping sets and eight hand lift and force pumps, with the necessary hose for pumping the water from the tanks to the water transport.*

The tanks should be placed near a metalled bye-road or cross road (not a main traffic artery) and filled by lengths of hose branching off from the 4-inch forward main.

A duplicate set of tanks, etc., is carried to establish a second point further forward without interrupting the supply to the water transport except during the period required to carry the pumps and hose from the rear to the new point.

The pumps and hose will remain in R.E. charge, but working the pumps for filling the water vehicles will be the duty of the personnel of the water transport.

21. *The first objective for each advance supply line has been fixed by the Army, and the points towards which the forward line should be aid further in advance will be similarly dealt with.*

Mobile Pumping Sets.

22. *The "Mobile" pumping sets that are being prepared are of two descriptions—deep-well pumps and pumps with ordinary suction (say to 25 ft.) and the details of these are given in the Appendices 3 and 4.**

One 3-ton lorry can carry the pump, petrol engine, and tubing for wells of 200 ft. in depth, complete, and the installation of the pump should not take more than 30 hours' work. The pump duty is 1,000 gallons per hour against a total combined head of 250 ft. through 4-inch piping.

*The other "Mobile" sets are mounted on wheels, and made up with sets as described in the Appendix 4.**

These are powerful pumps, some of the L.C.C. Fire engines being capable of delivering 10,000 gallons per hour through 1,000 yards of pipe against 150 ft. rise.

Reserve of Pumps.

23. *In addition to the "Mobile" sets as described in the Appendices, considerable number of pumps of various patterns, which would require a considerable time to instal, will be held in reserve. The numbers that will be available cannot be determined until the demands for the concentration and back areas are fulfilled.*

24. *The "Mobile" and reserve pumps will be held at one of the Parks, and applications for these should be sent to the Chief Engineer, Fourth Army*

* *Not reproduced here.*

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Composition of Fourth Army Water Column.

Part II.

1. *To meet the requirements of corps in connection with the transport of water from the forward water point to the water carts, No. 1 Water Tank Company, which has been allotted to the Fourth Army, will be augmented by a number of 3-ton lorries fitted with tanks and will comprise and be designated the Fourth Army Water Column. Each of the additional lorries is capable of carrying 550 gallons of water per trip.*

2. *The Army Water Column will be organized on the following lines:—*

The column will comprise headquarters and a number of sections, the number of the latter corresponding to the number of corps that are served by the column.

The headquarters will comprise the workshops and a percentage of each type of lorry.

3. *All demands to replace casualties to vehicles will be made direct on Army Water Column Headquarters.*

The personnel of each section will be, for the purpose of records, etc., on the strength of the company comprising the Army Water Column, i.e., No. 1 Water Tank M.T. Company.

4. *The total transport will be as follows —*

1-ton lorries—135 *gallons each.*
84 *present Water Tank Company.*
3 ,, —550 *gallons each.*
15 *present Water Tank Company.*
3 ,, —550 *gallons each.*
96 *now available.*
3 ,, —550 *gallons each.*
96 *probably available at a later date.*

The 1-ton lorries are capable of proceeding over light pontoons, hastily constructed bridges and bad roads.

5. *The following specially equipped lorries will be available for forming water points at ponds or wells additional to those on the advance supply lines in cases of emergency and where the water is too bad to be treated by water-carts or where it has been poisoned:—*

	No.	
Sterilizers	15—	*Output* = 400 *g.p.h.*
Depoisoners	9—	,, = 400 *g.p.h.*
First Aid Pumping Lorries ...		,, = 2000 *g.p.h.*

The first aid lorries carry a petrol pump, two 2,000-gallon canvas tanks and 900 feet of hose. They will be used in connection with the sterilizers and depoisoners when these appliances are unable to approach near the source of the water. These vehicles will be detached to corps as and when required and each section of eight lorries will be accompanied by a chemist.

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6. *Corps should base their demands for water on transport on the following table, which gives the results obtained on the recent trials with the Water Tank Company.*

The assumed rate of transport is :—

1-ton lorries—6 p.m.h.
3-ton lorries—4 m.p.h.

The total trips given allow for the average time lost at the forward water point and for discharging into water carts at the refilling points.

NUMBER OF TRIPS POSSIBLE PER 10-HOUR DAY.

Distance between F.W.P. and water carts ... ... Miles	2	4	6	8	10	12	14	16
No. of trips for 1-ton lorries ...	5	4	3	3	2	2	2	1
No. of trips for 3-ton lorries ...	4	3	2	2	1	1	1	1

7. *Sections detached from the Army Water Column will be equipped with motor-cycles, cars, spare 3-ton lorry for rations, etc., and spare drivers. They will always be accompanied by an officer and will form an independent sub-company.*

The Water Tank Company repair shops move with the headquarters of the Army Water Column and carry the necessary spare parts for both the 1-ton and 3-ton chassis of the Water Tank lorries, these latter being distinguished by the company sign (a sword fish).

All repairs to the improvised vehicles must, as far as possible, be done by corps, as the company workshops with Headquarters of the Army Water Column will not be in a position to undertake them in the case of vehicles actually detailed with corps.

8. *Sections should be billeted or bivouacked adjacent to the forward water points as far as possible.*

9. *All tank lorries are equipped with Dando hand pumps, and the necessary suction and delivery hose for off-loading into the water-carts.*

10. *The following points in connection with working the lorry transport and off-loading into water-carts are the result of experience gained during the recent trials.*

(*a*) *Convoys should not consist of more than six 3-ton lorries and ten 1-ton lorries.*

(*b*) *Water-carts should approach the refilling point from the opposite direction to the lorries.*

(*c*) *To avoid confusion separate refilling points should be allotted to the various convoys, or when this cannot be arranged and one pump has to be used, convoys must be allotted separate times for re-filling.*

(*d*) *Lorries should take up their position for off-loading before the carts move up.*

1-ton lorries should be lined up 15 yards apart.
3-ton ,, ,, 60 ,,
One 1-ton lorry will fill 1 water cart.
One 3-ton ,, ,, 5 water carts.

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11. *The water.carts should be detailed to take up their postionin the rear of their respective* 1-*ton lorries, and should each move off independently as soon as filled.*

12. *The five water-carts detailed for each* 3-*ton lorry should take up their positions, three in rear of, and two in front of, each lorry. These should also move off independently when filled.*

13. *All tank lorries will be numbered on their sides thus*:—28 (*figures enclosed in a circle*), *and the drivers of the water-carts should, wherever possible, be instructed as to the number of the lorry from which they will fill before they move up. This avoids confusion should there be heavy traffic on the road.*

The personnel of the water-carts must be instructed to assist in the pumping when water-carts are filled from lorries.

Appendices 3 and 4 gave detailed descriptions of the Duke and Ockenden tube well-pump sets, and the L.C.C. fire engine sets. These have already been described in Part I.

The list of wells referred to in para. 15 (page 60) above was contained in a 3-sheet supplement which gave a complete list of towns and villages between the River Ancre and the Canal-du-Nord, giving the altitude in metres, number of inhabitants per well, number of wells, and estimated depths of wells.

During the preparatory period prior to 1st of July a very large number of power installations were installed with rising mains up to five and even more miles in length, with more or less elaborate distribution systems. About 120 miles of mains were laid in all, and over 100 power pumps installed.

Two particularly useful lessons were learnt during the laying of one of the main forward systems. This was the Suzanne system, which consisted of two 4-inch mains, one to supply Carnoy ; the other to supply Talus Boisé.

The Carnoy main was originally laid in quick flanged joint pipe. This proved to be unsuitable material, as repairs could not be easily effected—firstly, because the pipes varied in length—secondly, because the pipes were too thin to stand the screwed thread. This type of piping was given up after this experience.

The Talus Boisé main had been laid from six to eight feet with the idea of protecting it against shell fire. Besides this the trench had been made use of for signal cables. The depth proved to be excessive, while affording no protection against a direct hit, and the signal cables were a great hindrance when repairs had to be made. As a result of this experience the depth of pipe laying was standardized to 2 ft. 6 in., and signal cables were no longer allowed to be laid in the same trench.

2. *Development after the Attack.*—After the attack and consequent advance the pipe systems were developed on the general lines indicated

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in the memorandum. The advance actually took place by stages, so that although several of the advanced lines were able to be rapidly pushed forward, and forward water points opened, the general scheme of carrying water to the divisional water-carts did not materialize.

The most successful pipe line in point of time was the extension of the Fricourt system, one water point being actually established at Fricourt within 12 hours of the taking of the village, the entire system being completed in about 10 days after the advance. The extension of the Suzanne system to Montauban could not be carried out on account of the continuous shelling of the valley, and had to be diverted. Various other minor alterations had also to be made in the original scheme.

When the guns began to move, horses for ammunition and supply columns were moved forward into the old German trench area, and these had to be watered in numbers far exceeding expectations. The result was that corps had to instal a vast number of horse watering points. The pumps erected for the advanced pipe lines were generally of insufficient power to cope with the additional horses, but the situation was saved by the use of L.C.C. fire engines and other pumps capable of discharging large quantities of water at low heads. At several horse watering points as many as 20,000 horses were watered daily; at one place a L.C.C. engine was observed pumping 10,000 gallons an hour direct into long ranges of troughs for hours at a time without ever being able to fill them.

Throughout the operations it was necessary for Divisional and Corps R.E. to develop new sources in the captured areas, and in spite of incessant shelling and daily breaches of the pipe lines, a considerable number of new wells varying in depth from 40 to 100 feet were sunk, whilst wells in captured villages were developed and pumping sets installed. Boring operations were also undertaken and a group of bore-holes was sunk to supply a pump capable of delivering 200 gallons a minute against 600 feet head.

The steady development of the forward pipe systems went on in accordance with further memorandums issued from Army Headquarters. This is illustrated on *Plates* I. and II.

The Suzanne springs began to give out towards the end of September, at a time when active operations on the Guillemont Plateau were being undertaken. A 4-inch main about one mile in length was quickly laid to the barge sterilizing unit on the river Somme and a pumping plant installed. The water was pumped into the spring chamber, and the supply thus replenished; the yield of the spring dropped from about 15,000 gallons per hour to 5,000 gallons per hour, and did not recover until January–February, 1917, when the further development of these systems was given up owing to the German retirement.

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The most interesting of the new systems was probably the Carnoy—Montauban—Guillemont. A series of five borings had been driven at Caftet Wood near Carnoy, which were intended to be worked by bore-hole pumping plants from the base workshops. These plants when received only proved capable of delivering about 2,000 gallons per hour. In their place a compressor plant was erected with a capacity of at least 10,000 gallons per hour. This plant, the first of its type to be used, proved most successful, and was afterwards extensively adopted throughout the armies.

The line for the 6-inch main to Montauban was set out on September 1st, and a working party of 500 cavalry dug the trench. The pipes were distributed along the track and pipe laying commenced on September 4th. Three gangs of eight men worked in two shifts, and the pipe line of 3,088 yards was completed with all connections on September 12th. The old British and German front line defences formed very difficult obstacles both as regards digging the trench and laying the pipe.

The other work included in this scheme was :—

(*a*) The construction of two engine houses.
(*b*) The installation of two bore-hole pumping plants.
(*c*) Two 9,000-gallon storage reservoirs at pumping station.
(*d*) Two 9,000-gallon storage reservoirs at Montauban.
(*e*) Two overhead tanks, 1,600 gallons each, at Montauban.
(*f*) Large horse water point with five troughs each 105 feet long, with brick rubble standings.
(*g*) Two overhead tanks, 1,600 gallons each, feeding horse troughs.
(*h*) The installation of a large pumping set (Denis-Gwynne high lift centrifugal)—capacity 10,000 gallons per hour, 600 feet lift, and engine house.

The Fargny-Mill system was an extensive one. The Sixth French Army laid out a large pumping station with three pipe lines :—

One (3″) for the supply of Mericourt
One (4″) for the broad gauge railway at Mericourt, and
One (4″) for extension to Trones Wood, with duplicate pumps, Aster-Berger type, 4,000 gallons per hour.

In addition the Fourth Army laid a 6-inch pipe line to Trones Wood with extension to Ginchy, and installed duplicate 3-throw ram pumps, Brown-Pearn, 7,500 gallons per hour. At the commencement, water from the Somme river was used, but later on springs were developed. This supply was carried through to Trones Wood and formed the main supply to the broad gauge railway.

It is of interest to note that at this time the pumping capacity of one corps area alone amounted to 750,000 gallons per day. The estimate of the normal daily requirements for one corps front during an advance was 200,000 gallons.

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At the height of the battle, water had to be provided for roughly 300,000 men and 150,000 horses. In order to cope with these large numbers, over 100,000 gallons had at one time to be carried by road in addition to pumping 1,250,000 gallons a day.

The principal administrative lesson of the Somme battle as regards water supply was the absolute necessity for centralized control of all schemes by the Chief Engineer of the Army, who required for this purpose to be in the closest touch with the general and administrative staffs, and to have an adequate special staff of his own.

3. *Work of Water Column during Battle.*—The following table gives the actual distribution of the water carrying transport :—

SOMME OPERATIONS, WATER-CARRYING TRANSPORT.

	No. of Corps.	M.T. Water Tank Co.			3-ton Lorries fitted with 550-gallon Tanks.	Additional Regimental Water-carts.	G.S. Wagons fitted with 200-gallon Tanks.
		1-ton Lorries.	3-ton Lorries.	Sets of Clarifying and Depoisoning Plant.			
At outset, June, 1916.							
Fourth Army	5	III	20	1*	192	160	165
Total		III	20		192	160	165
In July, 1916.							
Fourth Army	3	III	20	1*	157	80	120
Reserve Army ...	2	—	—	—	35	80	45
Total		III	20	1	192	160	165
In October, 1916.							
Fourth Army	3	III	20	1*	157‡	80	120
Fifth Army	4	III†	20†	1*	35	80	45
Third Army	—	—	—		48§		
Total		222	40	2	240	160	165

* 1 Set consists of 19 clarifying lorries.
11 depoisoning ,,

† Fifth Army used Headquarters and spare vehicles of the M.T. Water Tank Co. as a separate section, making four sections, and subsequently added improvised water tank lorries to bring up the number of sections to five (one in Army Reserve).

‡ 50 Lorries diverted to the carriage of stone.

§ Withdrawn to M.T. Reserve.
44 fitted with water tanks at St. Omer.
4 ,, , with VII. Corps, Third Army.

On *Plate* III. will be found a graph showing the delivery of water by the Army Water Column during the months of June, July and August.

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Chapter II.

GERMAN WITHDRAWAL TO HINDENBURG LINE, ARRAS, AND VIMY RIDGE.

4. *Development during Winter*, 1916-17.—Development of water supply both in back areas and in the captured territory proceeded steadily throughout the winter. Considerable readjustment in boundaries between armies took place during this period, and in January, 1917, the Fourth Army extended its right and took over from the French Army the district south of the river Somme as far as the river Luce.

The French system of water supply was on somewhat different lines to the British, and consisted generally of a very large number of small local pumping stations, rather than the extensive pipe systems based on a comparatively small number of large capacity stations, which was the principal aim of the British organization.

The effect of suddenly taking over some hundred additional pumping stations brought a great strain on the available skilled personnel, and hastened the formation of Army E. and M. Companies.

A feature of this winter was the long spell of abnormally cold weather in January and February, a period of great anxiety on account of the shallow pipe lines, the exposed position of water points, and the lightly built pumping stations. The following record of temperature during this period is of interest :—

Frost Period of Winter 1916-1917.

Minimum temperature recorded at Querrieu during the nights ending at 7 a.m.

Date.	On Ground. Degs. F.	4 feet Above Ground. Degs. F.
January 20th	28	28
21st	28	28
22nd	28	29
23rd	11	16
24th	11	15
25th	8	15
26th	8	13
27th	13	17
28th	17	17
29th	9	12
30th	3	10
31st	10	16

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Date.	On Ground. Degs. F.	4 feet Above Ground. Degs. F.
February 1st	4	8
2nd	12	12
3rd	–5	2
4th	–6	0
5th	0	4
6th	6	9
7th	14	16
8th	10	14
9th	8	12
10th	–2	6
11th	6	10
12th	4	9
13th	30	30
14th	21	24
15th	16	23
16th	14	23

On the 17th February the continuous frost broke and the thaw set in.

During this same period an interesting check was kept of the amount of water drunk by horses at Carnoy cavalry troughs :—

Return of Horse Watering at Carnoy Cavalry Troughs.

Date.	From 6.30 a.m. to 9 a.m.	From 9 a.m. to 1 p.m.	From 1 p.m. to 6 p.m.	Total of Horses.	Gallons water Supplied.
January 18th ...	2,040	2,560	2,625	7,225	11,500
,, 19th ...	2,020	2,946	3,012	7,978	11,000
,, 20th ...	2,259	2,863	2,598	7,720	11,000
,, 21st ...	2,064	2,855	3,084	8,003	17,000
,, 23rd ...	2,325	2,973	3,686	8,984	19,000
,, 24th ...	2,316	2,703	3,248	8,267	12,000
,, 25th ...	2,110	2,867	2,918	7,895	17,000

Total of Horses for 7 days, 56,072.
,, water supplied, 98,500.
Average consumption per horse per watering, 1¾ gallons.

From this it will be seen that during the very heavy frost horses only drank just over five gallons a day.

The problem of water supply in the event of a swifter advance than had hitherto taken place was being seriously considered. The next stage in the advance according to plan was to be in a north-easterly direction, which would have led the Fourth and Fifth Armies over a waterless track some 15 miles in depth.* It was well recognized that extensive pipe systems would not be feasible in the case of a rapid advance, and much attention was devoted to the development of well-boring apparatus, which resulted in the formation of special Boring Sections in March, 1917. A development of the air-lift was taken up about the same time.

* The line actually came to rest at about the middle of this expanse.

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5. *Preparations for the Battle of Arras.*—The Third Army began detailed preparations for a great attack on the Arras front early in 1917.

Owing to the large number of water courses, and the shallow depth to the water table in the area of concentration west of Arras, the water problem was much less difficult than in the regions further south, through which the Fourth and Fifth Armies had been fighting, and boring operations had not been undertaken to any large extent before the German retirement in March, 1917, which swung the right flank of the Third Army forward into the area described in the preceding paragraph.

By March an adequate number of power systems had been installed in the concentration area, and arrangements made for advanced supplies on very similar lines to those employed in the Somme battle. *Plate* IV., which was issued with a memorandum on advanced water supplies by Third Army Headquarters, shows in outline the main systems.

Generally speaking the advance pipe lines were run forward when the Arras battle opened on April 9th, much as indicated on this *Plate*, with the exception of certain alterations involved by the German withdrawal on the southern part of the Army front.

Arras Town Supply.—The steps taken to use the Arras town supply formed an interesting feature in the preparatory work on this front. The group of bore-holes in the springs from which the town supply is taken is reported to be the origin of the name " Artesian " (in Artois) for wells of this character.* Vauban is said to have built the masonry construction with groined arch roof which still stands over these bore-holes.

The pumping station survived the intense bombardments, and although situated in an exposed position and hit by shells several times, the steam boilers and pumps were never badly damaged. The French had put in a petrol centrifugal set underground for emergency work, and in April, 1917, the Third British Army installed a second centrifugal pump (Tangyro), giving a very large delivery against a comparatively small head as an additional stand-by.

In addition to providing long lengths of horse troughs in the suburbs and several water-cart filling points in the side streets of Arras, (which proved of the greatest value during the advance), the town supplies were laid into the extensive cave systems under Ronville and St. Sauveur suburbs, and 4-inch mains carried forward through the full length of each of these cave systems were actually brought to the surface in " No Man's Land." Relay pumps were installed in both the Ronville and St. Sauveur caves to boost the water

* This honour is also claimed for a well in Lillers. The Bethune—Lillers district is prolific in artesian wells, almost every large farm containing beautifully clear springing water.

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forward through the advanced mains which were pushed on immediately the attack was launched on April 9th. Distribution by tanks and taps was arranged in the cave cook-houses and dressing stations to supply the troops concentrated in the caves in readiness for the attack.

6. *German Withdrawal to the Hindenburg Line.*—On the front of the Fifth Army and the right of the Third Army, where the German withdrawal was deepest, the great difficulty lay not in the number of troops and horses to be watered, but in the scarcity of all surface water in the area.

The normal supplies consisted almost entirely of small ponds and deep wells in the villages. In many places these wells were from 150 to 250 feet deep, and the actual depth of water in the wells had been just sufficient for the needs of the inhabitants and no more.†

The Germans in their retirement had completely destroyed all the wells, both by blowing in the masonry and by throwing all sorts of refuse, carcases, etc., down the wells, so that even these limited supplies were cut off. The most urgent work of Divisional R.E. companies was the finding and opening up of these wells, work of the greatest difficulty owing to the completeness of the enemy's work of destruction.

It was at this time that the great need for a portable deep well hand pump was first felt; failing such a pump, divisions had to make shift at first with windlasses and buckets.

In the lower lying parts of the area water was occasionally found at from 12 to 20 feet deep, and many shallow wells were hastily sunk by Field Companies. This work was greatly facilitated by a plan of water level contours which had been prepared by the Geologist at G.H.Q. This same plan of course gave a useful indication of the depths at which water might be found in the existing damaged wells of the district.

As soon as it was possible for Corps and Army troops to come up, the best of the existing wells were further developed, and a number of belt pumps fixed; new bore-holes were sunk, and the installation of the necessary air compressor plant begun. As an example, on the Bapaume—Arras road near Sapignies a hole was started on the 25th March with a view to supplying a cavalry division. On the 2nd April large numbers of horses were actually watering at the water point which had been constructed while the hole was being driven. This spot is nearly at the summit of the Bapaume Plateau, and many miles from any surface water. This and other bores saved the situation—five bores put down during March and April delivered a total of some 400,000 gallons per day with no apparent loss of water level. These were all high level bores, the average depth being 100 metres.

† Exactly similar conditions were found to exist in the villages of Palestine.

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Map A. shows the new water points established by the Fifth Army in the area evacuated by the Germans in March, 1917, with the approximate front line before, and at the end of, the retirement.

Throughout the summer and autumn of 1917, during which period the Third Army gradually took over the whole area previously occupied by the Fourth and Fifth Armies, development proceeded on normal lines. The work already described had necessarily involved the making of an enormous number of new local water points, and with the gradual withdrawal of troops it became perfectly impossible for the technical personnel of one army to run all the plants. The general policy subsequent to active operations was therefore to link up supplies in the concentration areas, in order to reduce the number of pumping stations and economize personnel and at the same time to prepare installations close up to the new front in readiness for a further offensive. A great deal of work of an interesting character was carried out, of which the following are a few examples :—

MANANCOURT.

Source.—Springs.

Plant.—Four petrol centrifugal pumping sets, 7,500 g.p.h. 500 feet, to work in pairs—one pair being capable of supplying the full quantity required.

Supply.—By several rising mains to reservoirs on ridges some miles away, from which camps, etc., were fed by gravity distribution systems.

TUNNEL MOUTH.

At southern exit of the Canal-du-Nord Tunnel near Equancourt.

Source.—The bottom of the tunnel is just below sub-soil water level, having been constructed to feed this section of the canal, and by damming the southern exit a practically inexhaustible supply of pure water was available.

Plant and Supply.—Similar to Manancourt.

This pumping station would have compared favourably with many town supplies in civil practice.

HAPLINCOURT.

Source.—Bore-holes.

Plant.—Air-lift.

Supply.—At first an emergency supply to a large capacity canvas tank on the top of the débris of the destroyed village church near by, from which horse troughs, and water-cart filling points were fed by gravity. Later, a bricked pond was converted into a reservoir of large capacity and covered in, and fed direct by duplicate air-lifts. This reservoir fed an installation of petrol centrifugal pumps which

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supplied reservoirs in Haplincourt, Barastre, Bas, Rocquigny, and as far as the Bapaume—Peronne road, an area where large numbers of troops and horses were camped.

The long rising main which had been laid from Carnoy pumping station to the Ginchy heights during the Somme battle had, after the German retreat, been carried forward through Rocquigny to Barastre, etc., and by linking Haplincourt up with Barastre with a 4-inch main the Carnoy supply was relieved of the main part of its work. This enabled most of the long rising main between Trones Wood and the Bapaume—Peronne road to be taken up, as it passed through the area devastated in the Somme fighting, in which no troops could be camped.

VELU, BEHAGNIES, SAPIGNIES.

At these places and numerous others airlifts supplying 10,000 g.p.h. and over were working, and the powerful pumping plant at Aveluy near Albert raised large quantities of water by air-lift into local reservoirs from which the water was pumped to high level reservoirs at Pozières through a 6-inch rising main. Semi-Diesel engines furnished the main power at this station, and by linking up the Pozières reservoirs with some of the original rising mains carried forward during the early days of the Somme battle, water was supplied to salvage parties and to staging camps in a wide bend of the devastated area on both sides of the Albert—Peronne road. By this linking up of old rising mains water was distributed by gravity through considerably over 20 miles of 4-inch piping from the Pozières reservoirs.

The large increase of area and consequent new-water installations (at one time between 300 and 400 power plants were working in the Third Army area), caused a natural shortage of plant, and during the same period a number of water points in the old back areas were dismantled, pipe systems salved, and machinery and fittings sent forward for new work.

It could not be foreseen at that time that, within a year, many of these supplies would have been of the utmost value, after the great enemy attack of March, 1918; and, had they still existed, the water supply work in the summer of 1918 would have been materially lessened.

Map B shows the water points established during this period in a portion of the Third and Fourth Army areas. The original map was issued by the Fourth Army just before the final advance in 1918 to assist the troops in recovering old water points. See chapter IV., para. 14.

7. *Battle of Vimy Ridge.*—On the First Army front development of water supply in anticipation of a big offensive was taken in hand towards the end of 1916.

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The sources of water were almost without exception large springs emanating from the hill-sides, the district geologically being very prolific in water-bearing formation, viz. :—chalk flints and marl with an over-stratum of clay.

The actual Vimy Ridge, which was the object of any offensive, was entirely deficient of surface water, and extensive pipe systems were planned.

The estimated requirements were based originally on a concentration of 80,000 men at five gallons per head per day, and 36,000 horses at 10 gallons per head per day, making a total of 760,000 gallons per day required. To accomplish this 22 engines and 24 pumping installations were completed, 45 miles of piping were laid, 16 reservoirs of varying capacities were made, and the water distributed in sufficient quantities to the necessary horse watering points, water-bottle filling points, and water-cart filling points. In addition buried pipe lines were pushed forward to the close vicinity of the front line trenches in infantry sub-ways, to provide water for the troops and dressing stations.

A 50,000-gallon reservoir was excavated near Aux-Rietz with 25 feet of head cover, with additional accommodation for two engines and pumps, engine crews, repair shop, and stores. In Souchez valley a similar reservoir was excavated to tap a large spring, and deep dug-outs constructed for the engine room and crew. Reservoirs were also made off two of the main sub-ways, and the pipe line prepared ready to be carried forward with the advance. *Photo* I. shows a typical underground pumping station at Gavrelle.

After the capture of the Ridge, the development and extension of pipe line systems was carred out exactly in accordance with the pre-arranged schemes, but when the advance went on, and troops had to be located in large numbers on, and in front of, the Ridge itself, new sources of supply had to be opened up. This was done by means of a series of bore-holes and large airlift pumps, a method that had not been previously employed on this Army front.

The re-organization and development of the water supply arrangements in the area between the Arras—St. Pol road and the La Bassée canal on the north continued throughout the year 1916, in the course of which some 58 pumping stations were erected capable of delivering 155,000 gallons of water per hour.

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Chapter III.

MESSINES, PASSCHENDAELE AND CAMBRAI, 1917.

8. *Preparation for the Battle of Messines.*—In the Second Army area development of water supplies was carried on steadily through the winter of 1916 and the spring of 1917, in the course of which over 180 miles of piping had been laid, and pumping stations erected capable of supplying nearly 1,000,000 gallons of treated drinking water per day, and 500,000 gallons of un-treated water per day for horses.

In addition to the existing available storage supplies of Dickebusch and Zillebeke lakes and the moat at Ypres, in which a total supply of over 8,000,000 gallons was stored, about 10 clay reservoirs were constructed at various points along the Kemmel—Scherpenberg—Mont Rouge range of hills running roughly east and west through the centre of the area. From the dams thus constructed twelve gravity piped supplies were laid, giving over a quarter of a million gallons daily, with a reserve storage of over 6,000,000 gallons.

Shortly before the battle, a memorandum was issued by the Army on exactly similar lines to those issued before the Somme and Arras battles. The supply systems are described on *Plate* V., which was embodied in this memorandum.

As is well known the whole of the battle of Messines was carried through with the accuracy and punctuality of a peace time field day, and the pre-arranged development of the water supply was no exception in these respects.

In conjunction with all the work that had been carried out at this period in connection with the Messines offensive, the question of providing water to meet the needs of an army occupying the northern area, *i.e.*, between a line through Ypres up to a line west of Boesinghe to Roosbrugghe also had to be considered. (See *Map on Plate* V.) This area had been up to date generally occupied by the Belgian Army, and never having carried a heavy concentration of troops, very little water supply work had been done. Several deep-well bores had been sunk in the area without success, and only served to prove that some other solution of the problem would have to be found.

It was finally decided that water would have to be drawn entirely from the river Yser, and two large installations were planned at Haringhe and Roosbrugghe, where the water thus obtainable in

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unlimited quantity would be treated by mechanical means. The Haringhe waterworks has been fully described in Part I., chapter III., para. 38.

At Roosbrugghe a barrage was constructed on the river just below the main road bridge, to prevent the tidal waters mingling with the water thus stored, and a reach of the river was thus backed up to promote pre-sedimentation. From this reach 4-inch gravity pipes were laid to two sedimentation tanks each of 50,000 gallons capacity, where the water was treated with alum. After sedimentation the water was passed through mechanical sand filters of a capacity of 6,000 gallons an hour, being finally treated with chlorine gas, before passing to the pumps that delivered into the supply mains.

9. *Ypres—Passchendaele*, 1917.—The preparations for the attack of the 31st July on the Ypres front were taken over by the Fifth Army at the end of June.

The most important work in hand was the completion of the Haringhe system, which eventually supplied the major portion of the Army area. The exploitation of this system also involved work on a new boosting pumping station near Elverdinghe, and several forward water points. *Photos* II. and III. are exterior and interior views of this station. *Photo* IV. is an important water point on the system at Boesinghe.

As regards the water supply throughout the remainder of the Army area, attention was principally devoted to the digging of shallow wells for horse watering, a problem of pressing importance during a fortnight's drought; and to organizing the control of the supplies throughout the existing extensive pipe systems. Some of the latter supplied as many as three corps at a time, and owing to the frequent changes of corps areas control valves had to be taken over by the Army and placed in charge of a special officer. "Army Control Stations" were connected to A.H.Q. by telephone, and thus fairly even distribution of available water was effected between the various consumers.

The forward pipe lines which were to be pushed on after the advance, were :—

(*a*) Two lines—extensions of the Haringhe system—towards Langemarck,

(*b*) Two lines from Ypres in a north-easterly direction from pumps previously installed in a dug-out at Ypres swimming bath, and

(*c*) A line from the pump at Zillebeke Lake towards Hooge.

The first two lines were got nearly as far as the canal by "zero day." One of the lines from Ypres was got as far as Wieltje before the

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attack, by extraordinary efforts, but it was almost completely destroyed during the first day's fighting.

The line from Zillebeke Lake was taken almost to Birr cross-roads, but was completely destroyed during the night preceding the attack.

The intense and continuous shelling made it impossible, both during the preparatory period and during the battle, to maintain water-cart points or pipe lines within about 5,000 yards of the line. The furthest forward water-cart points supplied by pipe which could be maintained were situated at Boesinghe, Cheapside, Huddleston road, Noordhofwijk (near the canal bank), Ypres swimming bath and Zillebeke. Some small alum sedimentation plants were established on the Steenbeek, but were usually destroyed after being in operation for a day or two. A certain number of water points supplied by light railway were also made. A good example is shown on *Photo* V.

During the interval between the main Ypres and Passchendaele operations development was carried on in back areas, the chief work being a somewhat extensive pipe system supplying Corps schools at Millain, Bollezeele, Mercheghem, Volherinckhove, from a sterilizing barge on the canal at Schipstadt. Work was also continued on the Ypres waterworks. *Photo* VI. shows a dam in the Ypres canal—*Photos* VII. and VIII. are sedimentation tanks under construction.

Some boring work was also carried out during this period, but with no success owing to the difficulty of dealing with the Thanet sand. The " Ashford " tube had not at that time made its appearance.

In preparation for the battle of Passchendaele Ridge, the Second Army carried out considerable extension of the various forward water supplies ; in all 40 miles of piping with the necessary pumping plants were laid down, giving an additional supply of 100,000 gallons of drinking water per day.

The general details together with proposed extensions as existing in the middle of September, are described on *Plate* VI.

The advance to the Ridge proceeded by regular but limited stages, and shelling of the entire area continued to be so heavy throughout the fighting, that extension of pipe systems was a slow and onerous business. The fighting troops during their advance found a certain number of German wells, but these were destroyed by shell fire almost as soon as repaired, and practically all the advance supplies of water had to be taken forward by road.

10. *Coastal Area* (*Dunkerque to the River Yser*).—Early in July the Fourth Army had taken over a strip of coastal area from the French in anticipation of combined naval and military operations. The existing water supply in the area consisted of small isolated pumping stations, wells with hand pumps, and Norton tube wells. These had been sufficient during trench warfare conditions, but were quite inadequate for any concentration. *Map* C. shows the development

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of the Water Supply that was carried out by the Fourth Army in this area. The chief work was the extensive pipe line system stretching from Roosendael (Dunkerque) to the outskirts of Nieuport, probably the longest pipe line system constructed by the B.E.F. during the war. A contract was made with the Dunkerque Water Company for a supply of 100,000 to 150,000 gallons per day.

The water main in Roosendael was tapped, and from it three 40,000-gallon canvas sheet reservoirs were fed. A pumping station was then constructed in which were two 5,000 g.p.h. Hayward Tyler duplex pumping plants, with Cochrane boilers; these pumps delivered the water through a 4-inch main about 13 kilometres long to a point near Bray dunes, where a second pumping station was installed, consisting of four sets of Denis—Mather & Platt high lift centrifugal plants delivering 7,000 g.p.h. against 600 feet. From this station two 4-inch mains were carried forward, a coastal line and inland line. The coastal line delivered to reservoirs at Doornpanne; the inland line to reservoirs at Oost Dunkerque. At each of these two reservoirs pumping stations were designed to supply water forward to Nieuport, etc., but these stations were not finished at the time the proposed operations were abandoned.

An extensive water supply system was constructed for Le Clipon training camp by the use of sterilizing lorries and wells. A very careful check of the consumption of water by the troops gave a daily figure of between two and three gallons per head. Horses were watered from natural irrigation and drainage canals.

The most interesting feature of this coastal area from a Water Supply point of view was the sand dune formation which yielded fair quantities of water from shallow hand-dug wells. A small well of three to five feet diameter or square would yield from 500 to 1,000 gallons per day. A typical well of this description is shown on *Plate* VII.

The French and Belgians had sunk a few very large wells—for instance, at La Panne they had sunk three wells each of 30 feet diameter. These wells yielded 20,000 to 30,000 gallons a day.

Norton tube wells were not found a success. The standard 2-inch tube delivered very small quantities of water, while a locally constructed 4-inch type was difficult to drive, and hand-dug wells were found both simpler and better.

In preparation for the contemplated operations, special sea-going barges were provided. These barges were Thames sea-going lighters, fitted up with steel plate tanks and special low lift centrifugal pumps. The general arrangement of a barge is shown on *Plate* VIII. Eight of these were actually completed.

11. *Ypres Area during the Winter*, 1917.—As soon as the Passchendaele operations were finished, the Fourth Army, which had just handed over the coastal area to the French, took over both the

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Second and Fifth Army areas. The winter was spent in the maintenance of existing systems, and little new work was required.

The development of the Ypres swimming bath waterworks was carried on, and the construction of a concrete reservoir to contain about 80,000 gallons. A commencement was made with the laying of two 6-inch gravitation mains from Zillebeke Lake to Ypres, work which was not completed at the time of the subsequent German offensive. *Photo* IX. shows 6-inch pipe being laid.

The Second Army had already commenced the erection of a certain number of filters on the upward filtration system for improving supplies drawn from Dickebusch Lake and Ypres town moat. These filters, which are illustrated on *Plate* IX., were erected in pairs, and coupled by a 4-inch connection to a 400-gallon clear-water tank. Eight of these filters were erected in Dickebusch Lake, and four in the Ypres moat. The results of the filtration were quite satisfactory, and water subsequently required only the usual chlorination.

12. *The Battle of Cambrai, November, 1917* (*Map* B).—The greatest secrecy was observed in the whole of the preparations for this battle, the object of which was to surround and over-run a large tract of country by a *coup-de-main*. The nature of the operations made the more elaborate water supply methods of the Somme and other battles unsuitable, and the very short notice that could be given made all preparations difficult. A good deal was done by the Water Supply staff at Army Headquarters in preparing suitable mobile pumping plants, collecting water supply material in forward dumps, and setting the boring plants to work at selected forward sites in readiness to move into the captured area at the shortest notice.

Just before the attack was launched a conference was held of Corps Water Supply officers, Officers Commanding E. and M. Companies and Water Boring Sections, at which the Army W.S. officer explained the general scope of the proposed operations and expounded plans for special water reconnaissance to be made by selected officers accompanying the fighting troops. The schemes worked out at this conference proved most useful, and after the advance village supplies were very rapidly developed (hand pumps being used), while several German pumping stations were repaired and quickly put in action. Sites were selected for new bore-holes, and several drills were moved forward and commenced boring. One of these, which was working near La Vacquerie, was captured when the Germans counter attacked, as was another near Gouzeaucourt with an air compressor plant in the village, but both were recovered undamaged in the course of further British attacks during the next few days.

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Chapter IV.

1918 (See *Map* D.).

13. *German Offensive, March 21st,* 1918.—The great German advance in March and April of this year made an enormous amount of new work necessary, as not only had the areas actually occupied by troops to be supplied, but also extensive schemes for development of back areas had to be put in hand to meet the possibility of further retirement.

The following figures give some idea of the amount of work done by one of the Southern Armies alone.

During the period 1st April to 30th June 58 new pumping stations were erected, 36 bore-holes with an average depth of 250 feet each were sunk, 60 water-cart points and 4,000-ft. run of horse troughing were constructed, with an estimated capacity of one and a half to one and three-quarter million gallons per day, 35 miles of 4-inch pipe mains were laid.

In the Northern Army over sixty miles of 4-inch piping were laid within two months, and during the same time ten deep-well bores and 35 small installations were laid down, together with a large number of portable alum sedimentation plants at suitable places on the streams.

In another army no less than 70 new bore-holes were sunk in back areas, some in relation to rear zone defence lines and others in what might later become concentration areas. The policy was to select a suitable area from a tactical point of view, then to fix the actual site from a geological and engineering point of view: the bore-hole was then made and tested—if the yield proved sufficient it was prepared for use with mobile air compressors, and otherwise a tube-well pump of 1,000 or 3,000 g.p.h. capacity was installed. The fullest use was made of the expert advice of the geologist at G.H.Q., and successful results were obtained from practically all the holes.

The requirements of the Medical Department entailed a great deal of work. A large number of new Casualty Clearing Stations had to be built, and their sites, which were necessarily decided by questions of tactics and transport, were generally unfavourable from a water supply point of view. This meant the establishment of separate stations, for which it was very difficult to find the necessary personnel, The situation was gradually eased by the development of mobile compressors, a good many of which were in regular use before [illegible] of June.

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A lot of work was done in connection with water supply and water storage in the new rear zone defence lines, especially on those parts of the front where the front line had remained steady.

The new supplies were normally arranged for by means of bore-holes designed to be worked by mobile compressor plants. At the most important points direct pumping sets were installed in deep dug-outs. Storage tanks were also placed in defended localities or posts, the amount varying from 200 to 800 gallons according to the size of the post and number of men intended to occupy it.

Map E. shows the Water Supply systems in the First Army forward areas in August, 1918.

14. *Fourth Army Attack, August,* 1918.—The final phase of the war was inaugurated by the attack of the Fourth British Army in conjunction with the French Army on August 8th. This attack was launched with great secrecy and at very short notice, and was at first generally believed to have a purely limited objective, with the object of clearing the Amiens front before settling down for the winter. The success of these operations and the development of the general situation led to very much extended operations on the part of the whole Third and Fourth Armies, which began on 21st August, and gradually developed until the entire British front was in motion.

It stands to reason that a period of this sort could not be one of deliberate preparation or execution of water supply schemes, and in the short account that follows of the work done, although there are many points of interest, there is nothing novel; work followed familiar lines, and its records are unavoidably a matter mainly of statistics.

The most important piece of work done in preparation for this advance was the construction of a new pipe system towards Villers Brettoneux and the Bois de Gentelles. The work consisted in installing two high lift centrifugal sets, 6,000 g.p.h. at springs near Boves, and laying about five miles of 4-inch main, the erection of large water-points on the Amiens—Villers Brettoneux road and on the Bois de Gentelles bye-road, and the construction of reservoirs of 36,000 gallons capacity.

The rate of pipe laying was as follows :—

Date.	Trench Excavated. Yards.	Pipe laid. Yards.
August 2nd	1,000	—
,, 3rd	2,000	1,200
,, 4th	2,000	1,800
,, 5th	1,000	2,100
,, 6th	1,900	2,800
,, 7th	500	500
,, 8th Water pumped through main—		
Total ...	8,400 yards long.	

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It was possible before the attack took place to issue short notes on the water conditions in the area that was being attacked, and maps were also issued showing the old British bores and water stations that had been over-run by the enemy during March and April. (See *Map* B.).

When the advance took place practically all the old water points were recovered, many of them intact, and many others requiring only minor repairs or new engines. The most important of the earliest to be recovered were those in the Mametz valley and Caterpillar valley. In one case the boilers were actually found under steam.

These stations each had a capacity of 4,000 to 8,000 g.p.h., and had they been destroyed by the enemy, the water situation on the Army left would have been very difficult.

The pipe line systems were quickly repaired. The old Fargny Mill system was reinstated with two sets of high-lift centrifugal pumps, 7,200 g.p.h., and served to maintain the broad gauge railway supply.

15. *General British Advance.*—Very soon after this successful advance confidential information was given to the Engineer-in-Chief of a proposed advance on a very much bigger scale. This involved the crossing of the practically waterless plateau between the river Ancre and the river Escaut, varying from 12 to 20 miles in breadth This area consists mainly of chalk downs admirably suited for boring but absolutely devoid of surface supplies. It was obvious that the supply of water to a force, which was estimated to amount to approximately 600,000 men and 300,000 horses, would be a matter of the greatest difficulty, and would have to depend, at any rate for a certain period, mainly on water that could be carried.

A detailed scheme was worked out in the Engineer-in-Chief's office which showed the amount of additional transport that would be required by the two armies engaged, and this scheme was handed over to the Q.M.G. department, which at once took steps to make the necessary arrangements

In addition to the regular Water Tank Companies, large numbers of ordinary 3-ton lorries and G.S. wagons were fitted up with water-carrying appliances ; further arrangements were made for considerable quantities of water to be carried forward both by broad gauge and light railways.

A map was prepared by the geologist on the Engineer-in-Chief's staff which described the peculiar characteristics of all the various districts to a considerable depth on the British front. *Map* D. is a copy of this map, together with the explanatory details. The British fronts on March 31st, August 8th, and November 11th have been added to this map in order to make it easier to trace the course of the operations. A second map was issued at this time on which every

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water-course that was known to actually contain water was clearly marked.

As far as possible further water-level contour maps were also prepared, but sufficient geological information was available for only small portions of the area.

These maps were distributed in considerable quantities before the general advance began, and were found of great value by Army and Corps Water Supply officers, who were responsible for working out schemes ahead. In the course of the advance of the Third Army an interesting series of German Water Supply maps was captured, one of which is reproduced (*Map* F.). These maps showed that the enemy had made use of the old British systems with the addition of very little new pipe line.

The most critical period in the advance was that between 21st August and 7th September, after which date further sources were available from the section of the Canal-du-Nord south of Hermies, and shallow wells in the dry valleys of the Cojeul and Sensée rivers; but what really saved the situation, and was mainly repsonsible for the fact that there was never any genuine shortage of water for the huge forces engaged, was the recovery of the old British bore-holes, and the extensive and successful use of mobile compressor plants at these bores. *Photo* X. shows a typical water point worked by a compressor lorry.

The following table will give some idea of the work done by the compressor lorries in one Army area alone. This army had thirteen plants, of which ten or eleven were often simultaneously in action :—

Week ending.	Number of points operated.	Water raised— Gallons.
10th August	11	1,800,000
17th ,, ...	11	1,977,000
24th ,, ...	14	3,291,000
31st ,, ...	24	4,801,000
7th September ...	20	4,677,000
14th ,, ...	19	3,382,000

The falling off in the last week was due to the fact that a certain number of stationary plants had been installed during a pause in the advance.

From careful records that were kept of petrol consumption the following interesting figures were obtained :—

Actual gallons of water pumped per gallon of petrol used.

Week ending.	Third Army.	Fourth Army.
27th July	2,480	1,760
3rd August	2,470	1,920
10th ,, ...	2,380	1,870

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The figures for petrol consumption used in calculating these results include the petrol both for pumping and for travelling on the road. The lower figures for Fourth Army were due mainly to the higher mileage travelled.

Once the line of the Escaut and St. Quentin canal was reached the greatest difficulties were over, but very heavy work had to be done in the rapid installation of new stations.

The Fourth Army still had difficult country to cross between the St. Quentin canal and the river Selle, and had to again depend very largely on water transport.

16. *Water Tank Companies during the Final Advance.*—The following table shows the distribution of the four Water Tank Companies at the middle of October :—

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ALLOTMENT OF WATER TANK COMPANIES—OCTOBER 15TH, 1918.

AREA.	No. 1 Co.			No. 2 Co.			No. 3 Co.			No. 4 Co.			No. of Lorries.			REMARKS.
	H.Q.	Water Secs.	Sterilizing Secs.	H.Q.	Water Secs.	Sterilizing Secs.	H.Q.	Water Secs.	Sterilizing Secs.	H.Q.	Water Secs.	Sterilizing Secs.	Car—Fords.	3-ton.	Sterilizing.	
Second Army				H.Q.	1	H.Q.1.			2				53	10	22	(*a*) 5 3-ton lorries fitted with compressor plants.
Fifth Army ...					1	1							20	5	8	
First Army ...					1						2	1	87	15	4	(*b*) 3 3-ton lorries —ditto.
Third Army...		1 (*a*)				1	H.Q.	5 (*d*)	1				220	39	15	(*c*) 3 3-ton lorries —ditto.
Fourth Army	H.Q. (*c*)	1 (*b*) 1	2 1					1				1	91	20	30	(*d*) 4 3-ton lorries —ditto.
L. of C. ...										R H.Q.	R 4 (*e*)	R 1	162	29	7	(*e*) One section *en route* from England.

R. denotes G.H.Q. Reserve.

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The amount of water actually carried by road transport is impossible to give accurately, but from various records that were kept it is safe to say that the total during the last four months of active fighting, must have been well over twenty million gallons.

The most important lesson that was learnt as regards the use of these companies was that they should be regarded as a means of establishing mobile water points, and not as merely a means of carrying water to units or formations. The practice of using them in this latter way had a tendency to creep in as a matter of convenience during stationary warfare, but it was found to be uneconomical, and during active operations was absolutely unreliable. From this it follows that control of the work of the companies had to be in the hands of a responsible Water Supply officer, that is to say the representative of the Chief Engineer of either Army or Corps. The organization to this end varied considerably in Armies. The system in one Army, in which the whole of the control was vested in the Chief Engineer, was as follows:

Each available section of a Water Tank Company was allotted a definite forward area in which to work—these areas generally, but not necessarily, conforming to Corps areas. The Corps Water Supply officer fixed at convenient points along lorry roads 400-gallon tanks with water-bottle fillers attached, and informed the officer in charge of the Water Tank Section in that area the exact position of each tank. It then became the duty of the Water Tank Section to fill these tanks, and to keep them filled at all times. If any tank was found not to have been used during any 24 hours, or became a casualty, further supply was stopped and the Corps Water officer informed. In this way lorries automatically closed down useless and out-of-date water points and became available for more forward duty with a minimum of supervision.

The general control was in the hands of the Army Water Supply officer, by whom the allotment of sections was varied as necessary.

17. *Conclusion.*—The problem in front of the Northern Armies as they were gradually drawn into the general advance was an entirely different one. Here there were ample surface supplies everywhere, and purification was therefore the most pressing work. For this purpose fullest use was made of the available sterilizing lorries of the Water Tank Companies, and very large numbers of portable alum sedimentation plants were erected.

In almost all the large towns that were occupied—Cambrai, Douai, Lille, etc., it was found that much damage had been done by the enemy, before their retreat, to the local waterworks. As soon as possible work was started on repairs of the main systems, but in several cases (Cambrai was a noticeable example), the damage was so extensive that it was found necessary to develop new sources rather than endeavour to put the old systems into commission. The

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supply of large numbers of civilian inhabitants added to the work, but all difficulties were successfully surmounted, and no instance of real shortage of water is known. *Photo* XI. shows a water supply bridge at Neuville, and *Photo* XII. part of the Denain main supply pipe.

Map G. shows the water points developed in the Fourth Army area from April to November, and *Map* H. in the Third Army area from August to November, 1918. A study of these maps will probably give the reader a clearer idea than any written account can do of the extent of the work that was accomplished.

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PLATE I.

'H ARMY.

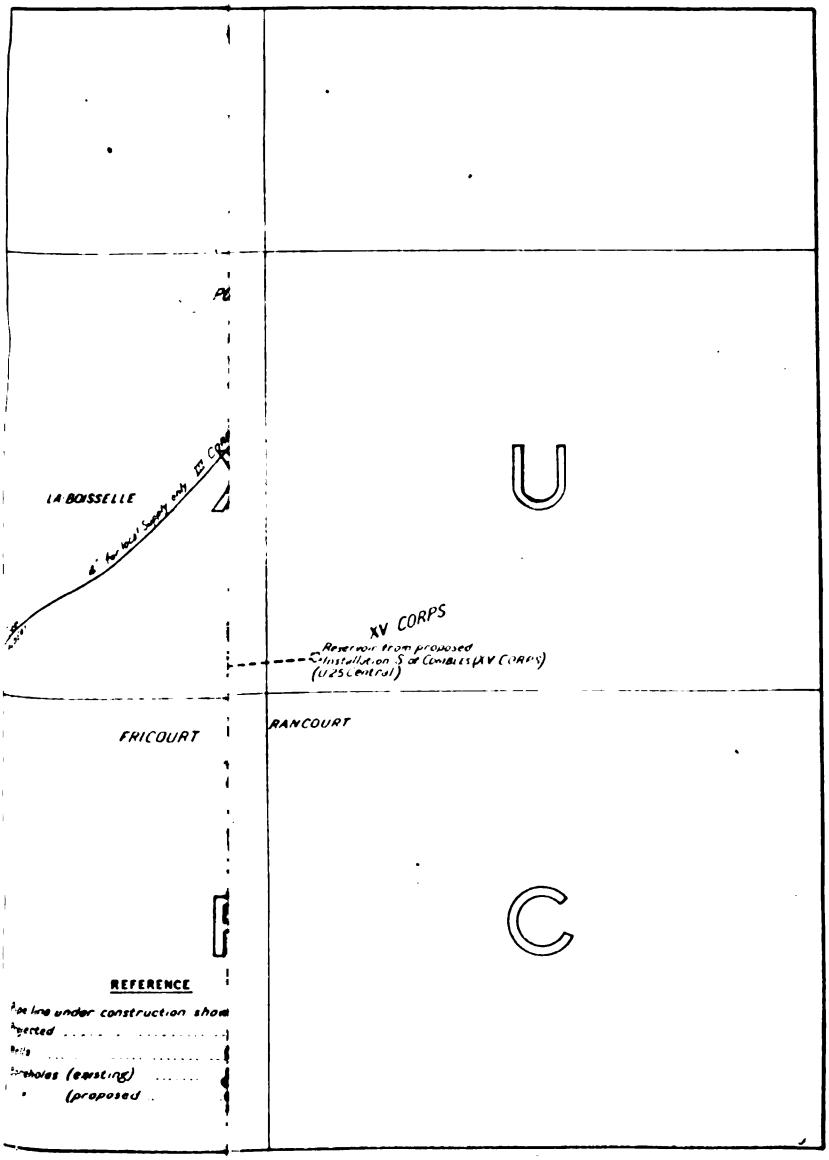

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PLATE II.

FMY.

DIAGRAM OF WATER MS IN FORWARD AREAS.

116.

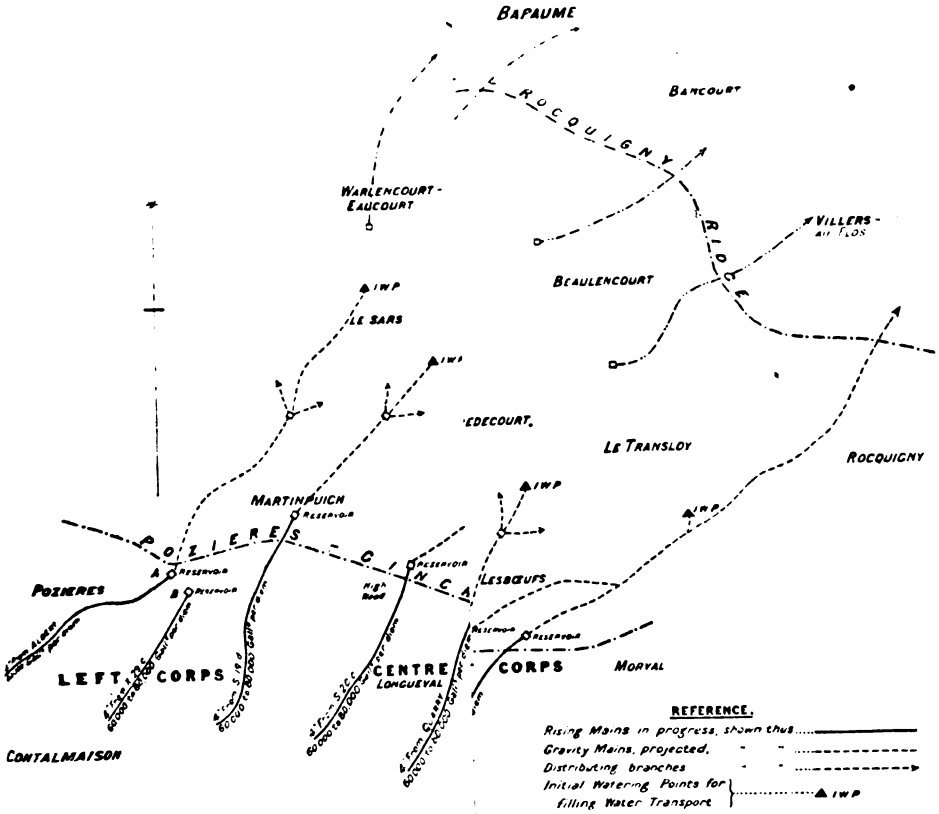

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PLATE II.

FOURT

DIAGRAM OF WATER SUPPLY FOR WARD AREAS
NOVEM

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PLATE IIA.

INDEX M

OURTH ARMY. ADVANCER SUPPLY.

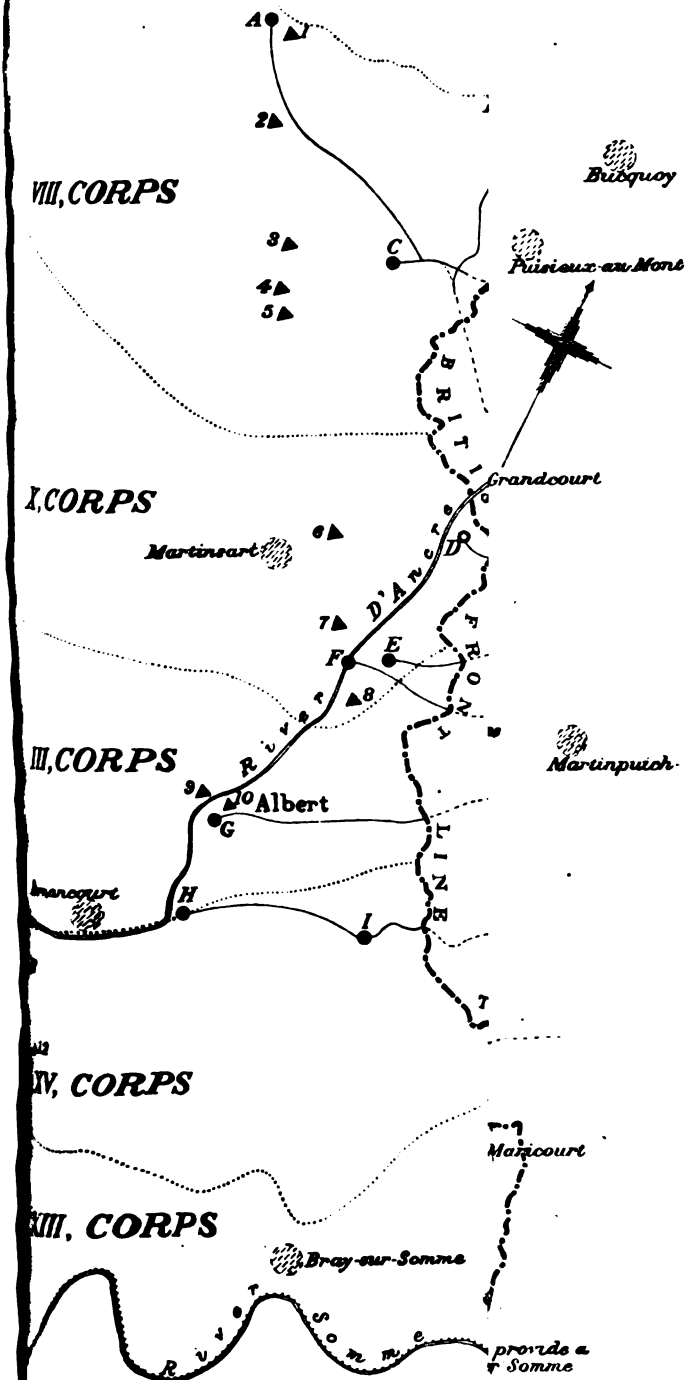

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PLATE II.

FOURT

DIAGRAM OF WATER SUPPLY FOR WARD AREAS.

NOVEM

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PLATE IIA.

INDEX M

OURTH ARMY. ADVANCER SUPPLY.

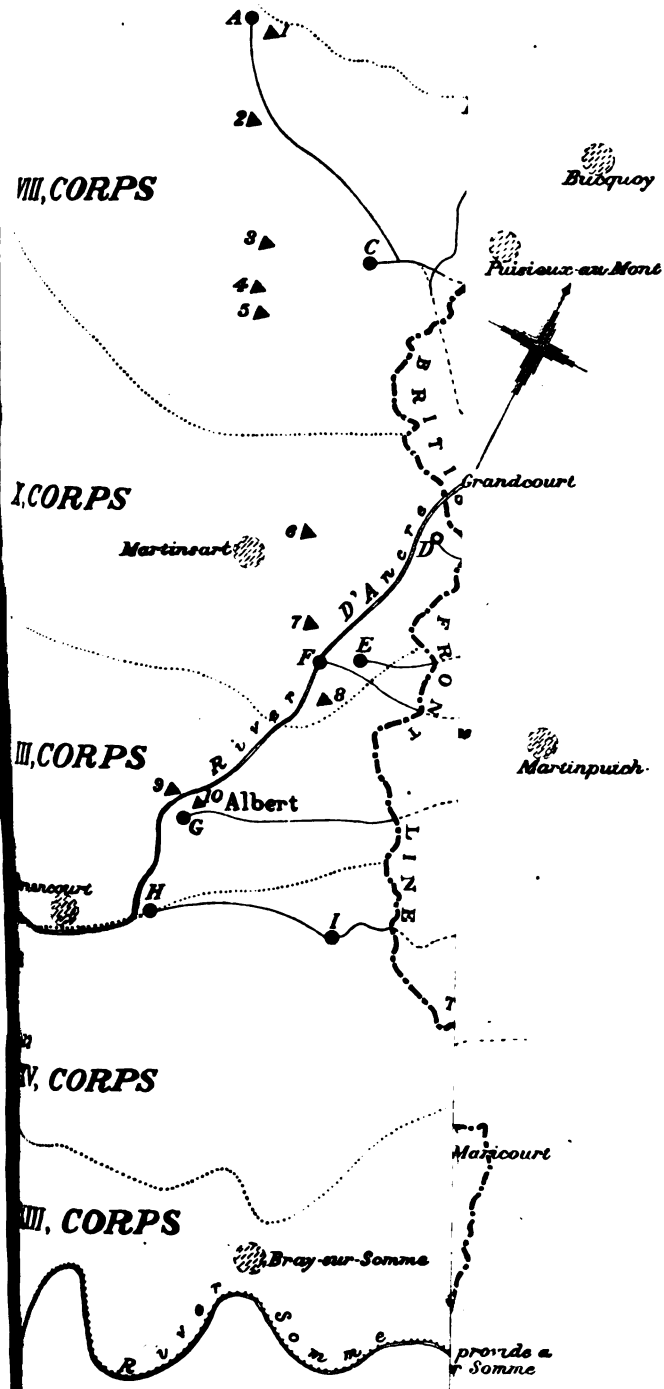

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PLATE III

FOURTH ARMY WATERLOO

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PLATE IV.

INDEX MAP. MARCH, 1917.

THIRD ARMY. ADVANCE WATER SUPPLY.

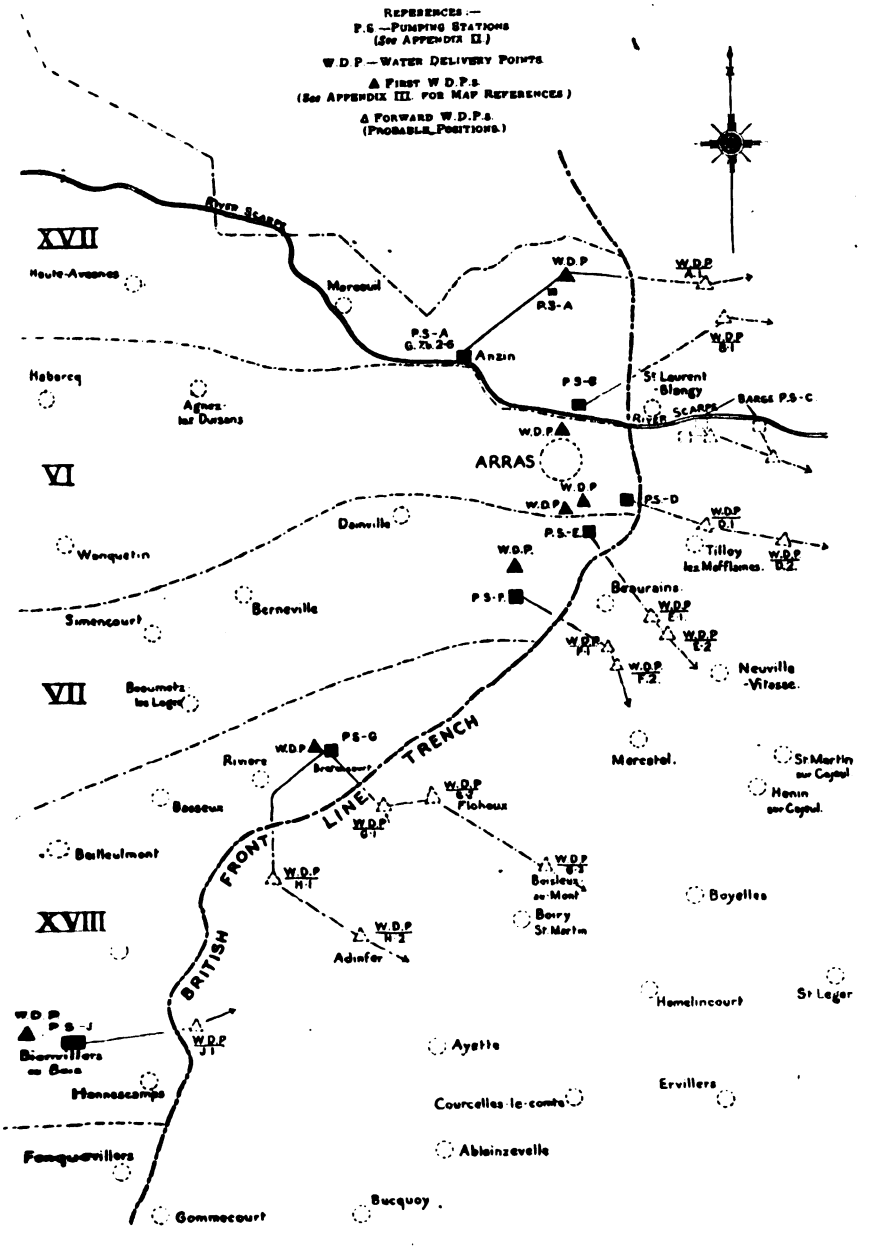

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PLATE V.
MAY, 1917.

FIRST WATER NDEX MAP.
(Sout
SHOWN THUS
ADVANCE WATER SUPPLY.

Situation.	
Near the Brasserie on the Ypres—Vierstraat road.	
Near Parrot Farm on the Kemmel—Vierstraat road.	
Near Rossignol Farm on the Kemmel—Vierstraat road.	
At Lindenhoek cross roads.	
Near Laynebok Brasserie on the Neuve Eglise—Kemmel road.	
Ditto.	
Wulverghem.	

Note.—There are numerous Wa

SOUTH
ADVANCED PUMPING
POSITIONS OF FORWAR
SHOWN THUS

Station Index Letter.	Corps Area.	Name and Map reference Pumping Station.	No. of Pumps.
A.	Hooge	Zillebeke.	1
B.	X.	Zillebeke.	1
C.	X.	Dickebusch Lake sluice gates.	1
D.	IX.	Ditto.	1
E.	IX.	Kemmel.	1
F.	IX.	Kemmel Hill gravity supply.	1
G.	II.	Wulverghem.	1

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PLATE VI.

WATER SUPPLY.

F

SH ONS.

AP

At Y. Wood, Ypres—Ghelu	utput tions; urs'	REMARKS.
Near Zouave Wng in	ns.	
Near Hooge.		
Near Voormezee	ooo	Pump to be installed as soon as possible after advance. "B" Pump Station serving this line at present.
Near St. Eloi.		
On the St. Eloi	ooo	Pipe lines unable to be maintained till after the advance.
Near the Brasse road.		
Near Plateau Wytschaete ro	ooo	Same as for "B."
At Unnamed Wytschaete ro	ooo	Also feeds 2-inch line to Tank at Voormezeele for X. Corps.
Near Ouraet Fa road.		
Near Parrot Far road.	ooo	Inter-changeable with "D."
Near Rossignol Vierstraat roa	ooo	
Near Maedelsted Wytschaete ro	ooo	
Near Wytschaet		
At Lindenhoek	ooo	
Near De Kenne Kemmel road.		
Near De Kenne Kemmel road.	ooo	Boving & Co. petrol driven set as stand-by.
Near Wulverghe		
On the Wulver		
Near Stinking F		
Near Réd Lodg		

Note.—T

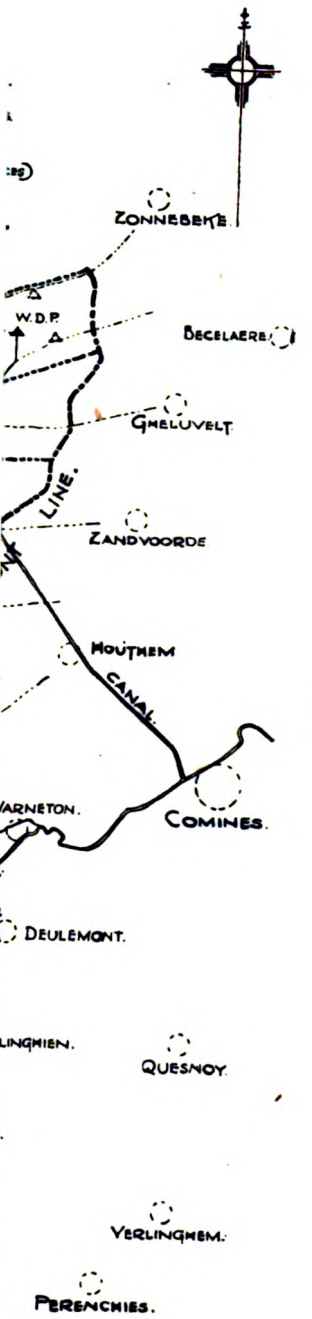

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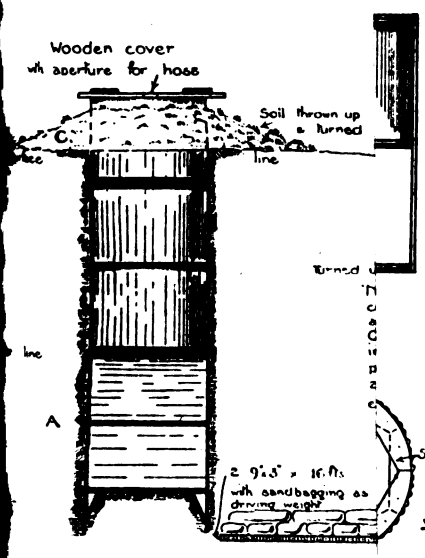
PLATE VII.

TYPE SUNK BY 23RD LIPON CAMP. JULY, 1917.



PLAN SHEWING
SEGMENTAL COLLAR

C

This Section was used in lieu of a 6'0" one for the reason that a sufficient depth of water having been aquired. a 6'0" section would make height above ground too much

6' sheets of Corr Iron

Ground line

QUANTITIES

for A or B Sections

No { 9 sheets Corr iron 6'0" long
. { 36 ft run 5'x1' for Collars
. { 1lb 3" Nails

for Wedges & Apron to A Section

No { 13 ft run 5'x2' making 26. 1ft wedges
. { 1 sheet Corr iron cut into 4 strips of 1'6" and hammered out, cut & fitted as apron

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PLATE VII.

W

THE SUNS BY ZOBO FIELD CO., 1 JULY, 1917.

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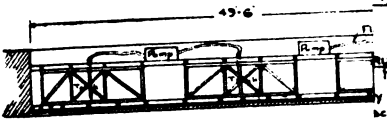
PLATE VIII.

ARRANGEMENT ANSEA - GOING BARGES.

- ARRANGEMENT OF TANKS FITTED WITH T. LENOX PRESSED STEEL TANK (Sectional)

...ity 3700 Gallons

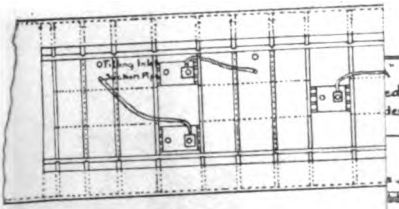


...STIONS FOR ERECTION

...together the Nine Bottom Sections first

...y a layer of the Jointing Compound about 2" wide & 1/8 thick ...ach joint before bolting.

... all the bolts are pulled up tight, press into the joints the ...ound which has squeezed out.

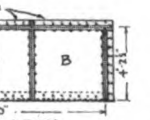


TYPES OF PLATES USED

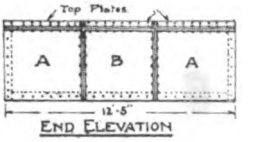
Type "B" Flanged on 3 sides

Type "C" Flanged on 4 sides

Barges Fitted :- Beta.
Alicia.
Coal.
Firefly.
Lancer.
Nizam.
Sirdar.
Summer



...EVATION

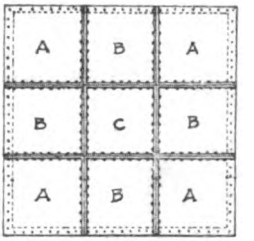


END ELEVATION

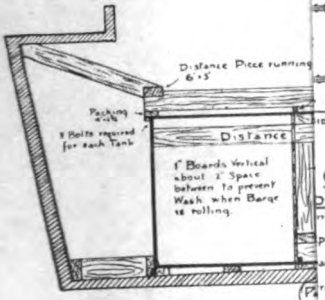
SECTION THRO' BARGE SH...

Note :- Pump Inlet & Outlet Pipes o...

...BOTTOM ...SIDE)



PLAN OF TOP


Distance Piece running
6'·5"
Packing
8 Bolts required for each Tank
Distance
1" Boards Vertical about 2" Space between to prevent Wash when Barge is rolling.

CONTENTS OF BARGE

...D

...ne Pumps		5
...pressed steel 3,700 gallons capacity		3
...and, "Beck" Type.		1
...rs, hose		2
(Delivery, armoured	feet	360
" canvas	yards	20
(Suction, armoured	lengths	4

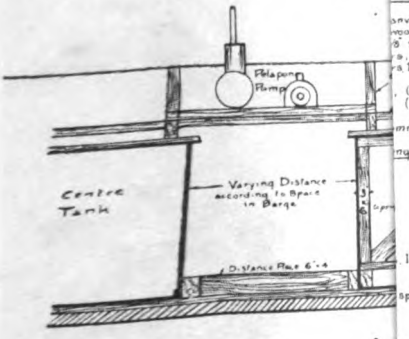
CRO...

...RD BULKHEAD

...anvas in wooden box, 2,500 gallons capacity	1
...wooden, to carry Tank (erected on Site) Drawing No W 841	1
...8 Spare	36
...s, 5/8"	2
...s Hand, Fitter's	1
... (flat	1
... (round nosed	1
	2
...mmy	2

...ngine, in box.

(Adjustable	1
(Footprints	1
(Box ¼"	1
(3/16 & ¼"	1
(5/16 & 3/8	1
(½ & 5/8"	1
Inlet, Exhaust, Governor. 1 each	3
(Exhaust) Chamber	12
...spare. (Water Jacket	3
(Pump (leather)	1
(Carburettor	1
...are	1
... Plugs spare	1
...iver	2
	1



L...

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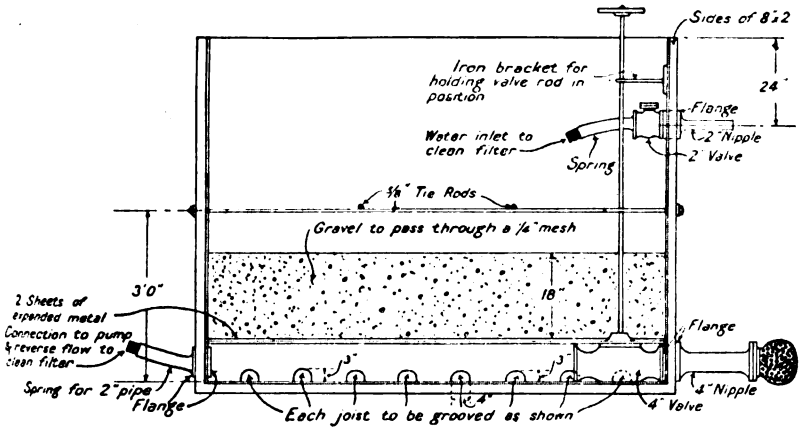
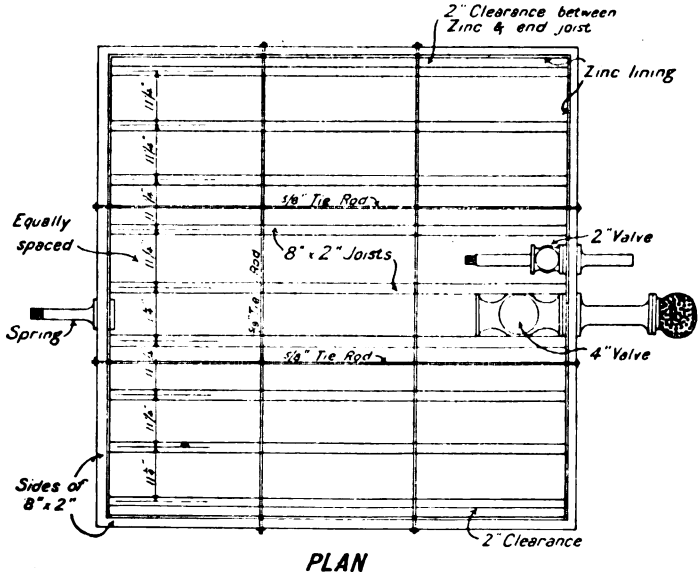
PLATE IX.

FILTER BOX. UPWARD FILTRATION.

INSIDE SIZE 8 ft. × 8 ft. × 6 ft. DEEP.



SECTION



PLAN

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Photograph I.—Underground Pumping Station, Gavrelle

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Photograph II.—Exterior of Boosting Station near Elverdinghe.

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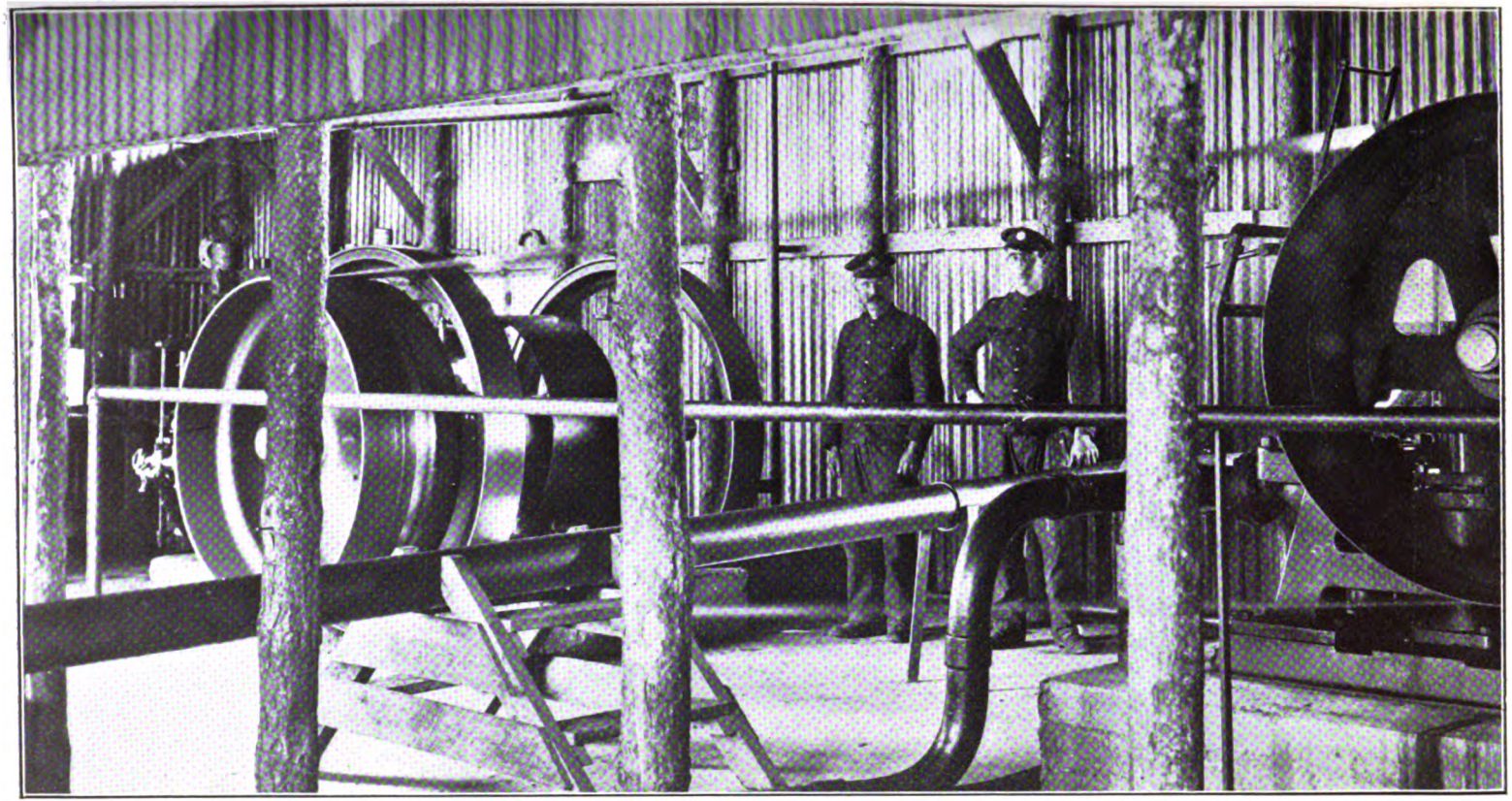

Photograph III.– Interior of Boosting Station at Elverdinghe.

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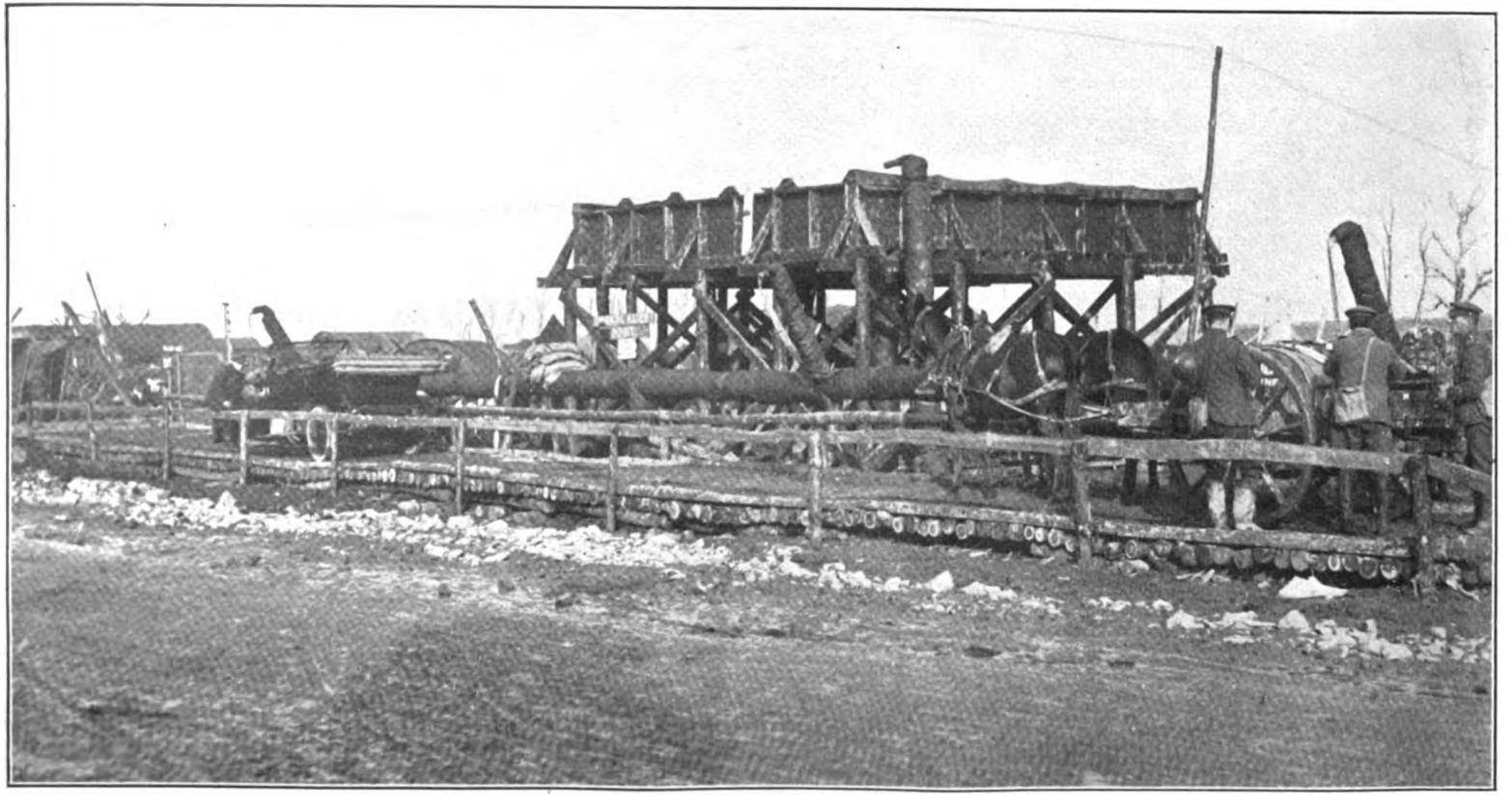

Photograph IV. —Boesinghe Water-point.

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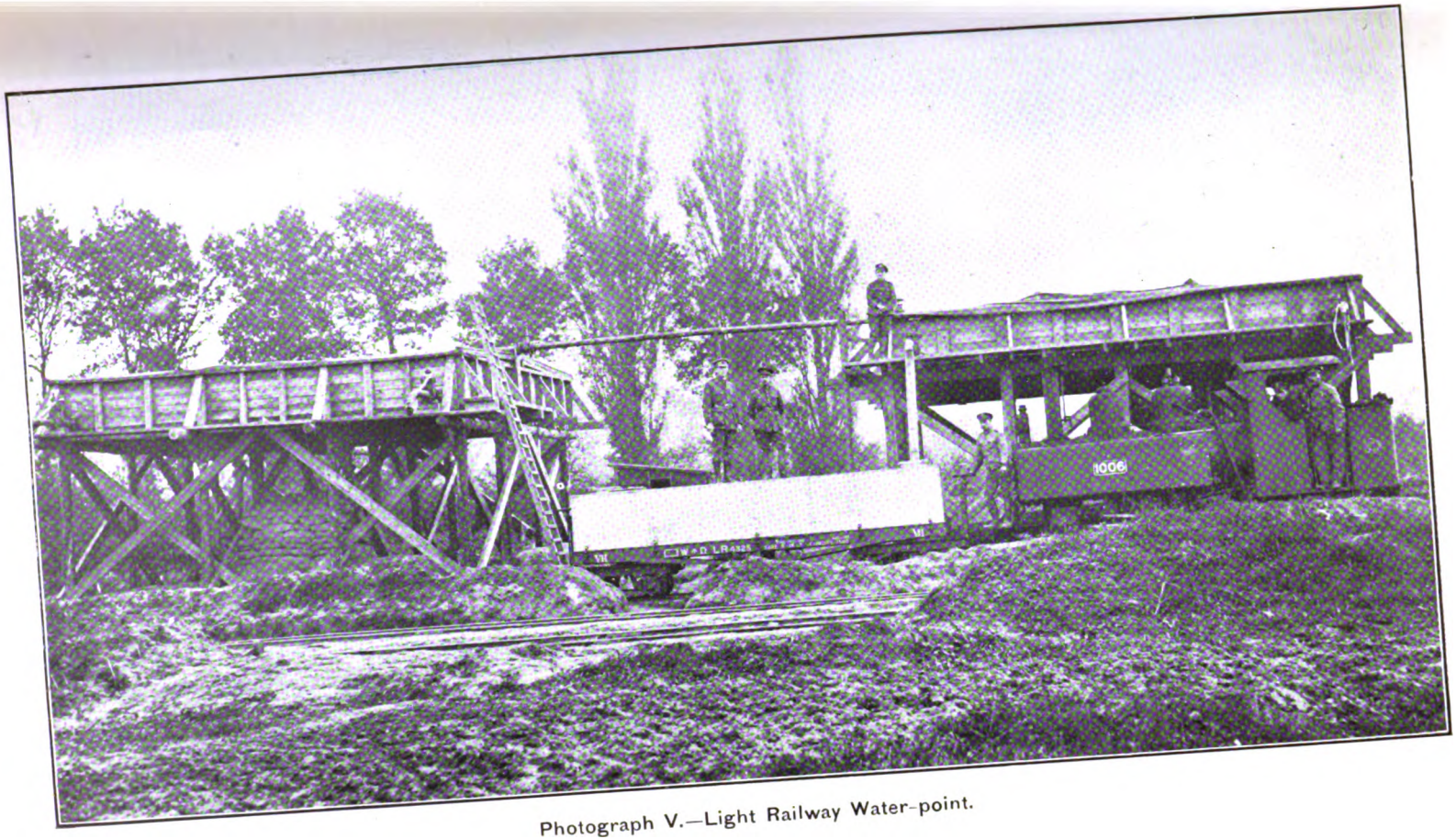

Photograph V.—Light Railway Water-point.

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Photograph VII.—Sedimentation Tanks under construction, Ypres Water-works.

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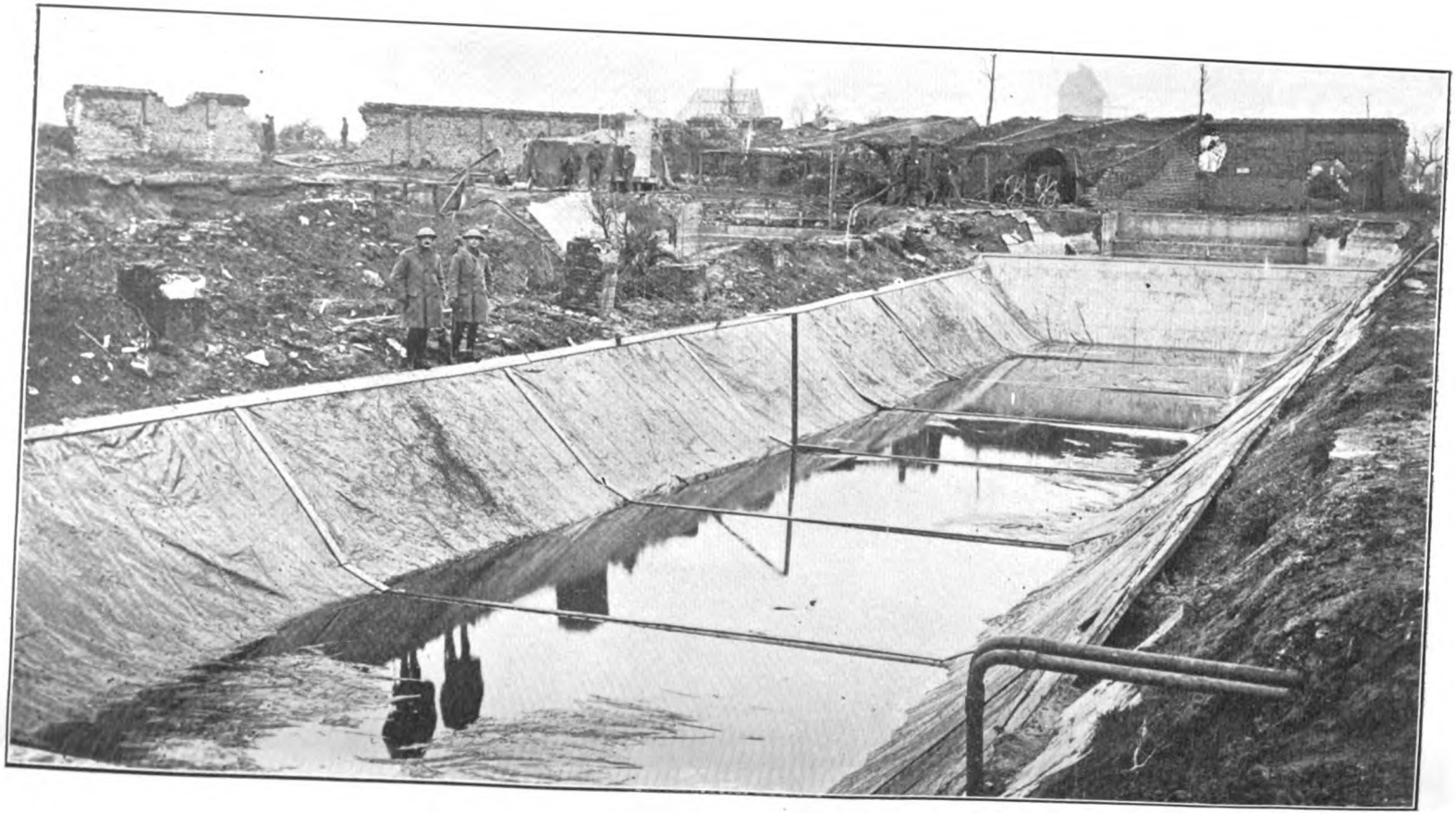

Photograph VIII.—Sedimentation Tanks, Ypres Water-works.

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Photograph IX.—Laying 6 inch pipe.

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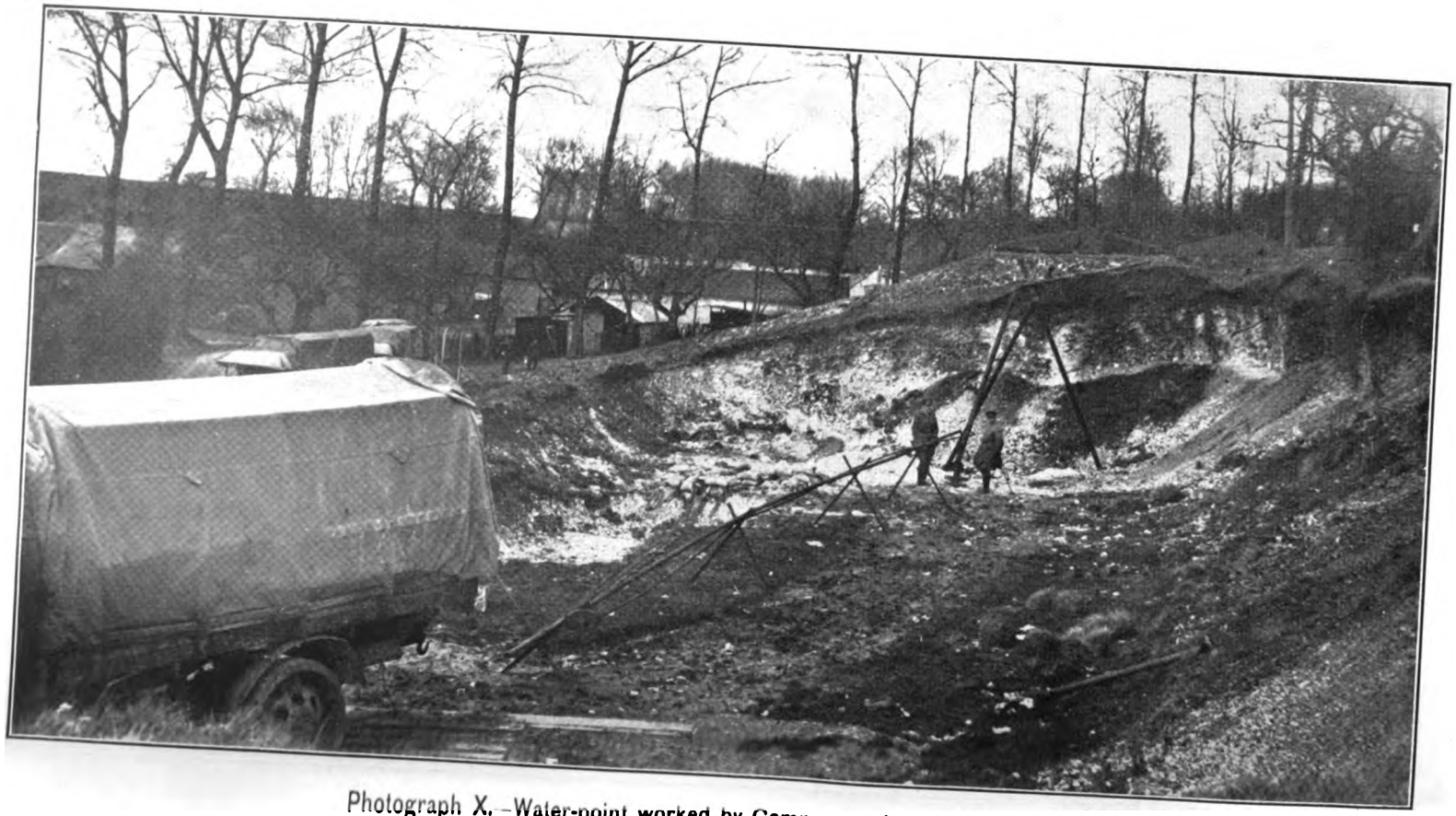

Photograph X.—Water-point worked by Compressor Lorry, La Vicogne.

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Photograph XI.—Water supply bridge at Neuville.

Photograph XII.—Water supply bridge at Denain.

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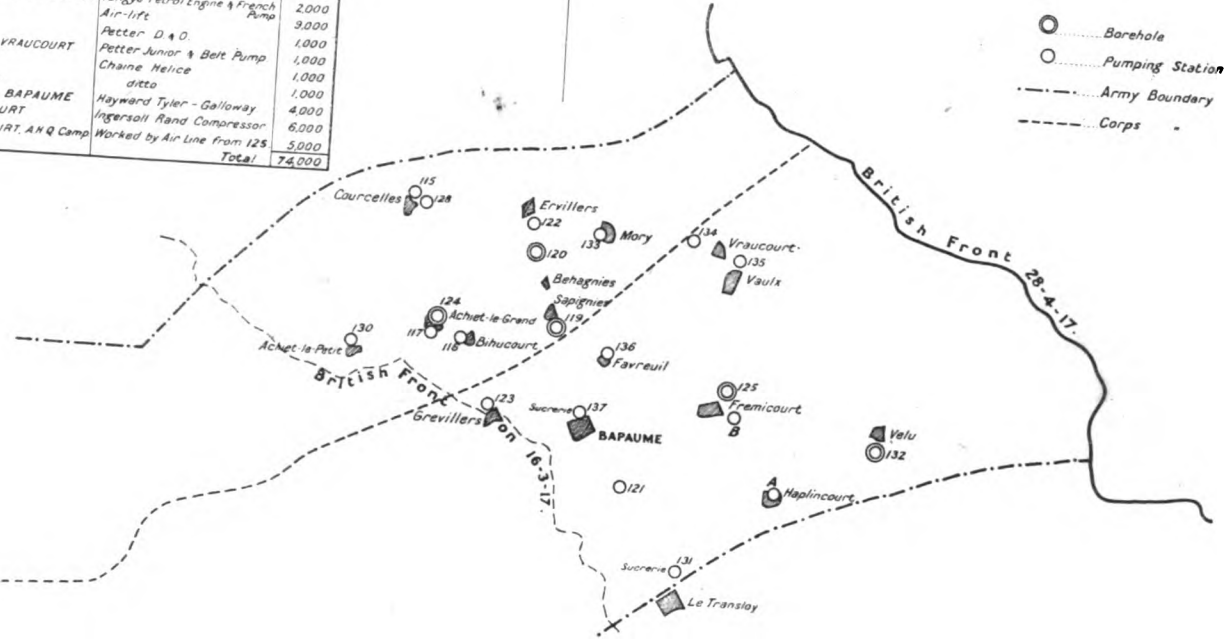
NEW WATER POINTS.
FIFTH ARMY MARCH—APRIL. 1917.

Number	Place	Plant	Capacity in Gallons
117	BIHUCOURT	ditto	1,000
118	ACHIET-le-Grand	ditto	1,000
119	SAPIGNIES	Ingersoll Rand, Compressor	8,000
120	BEHAGNIES	ditto	11,000
121	BAPAUME	Spencer Boiler & Merryweather N°2 Pump	3,000
122	ERVILLERS	Helice and engine	1,000
123	GREVILLERS	Petter D & O	1,000
124	ACHIET-le-Grand	Air-lift plant	8,000
125	FREMICOURT	ditto	7,000
126	COURCELLES	Duke & Ockenden	1,000
130	ACHIET-le-Petit	Power Chaine Helice	1,000
131	Sucrerie, N°LE TRANSLOY	Tangye Petrol Engine & French Pump	2,000
132	VELU	Air-lift	3,000
133	MORY	Petter D & O	1,000
134	Sucrerie, VRAUCOURT	Petter Junior & Belt Pump	1,000
135	VAULX	Chaine Helice	1,000
136	FAVREUIL	ditto	1,000
137	Sucrerie, BAPAUME	Hayward Tyler - Galloway	4,000
A	HAPLINCOURT	Ingersoll Rand Compressor	6,000
B	FREMICOURT, A.N.Q. Camp	Worked by Air Line from 125	5,000
		Total	74,000



MAP 'A.'

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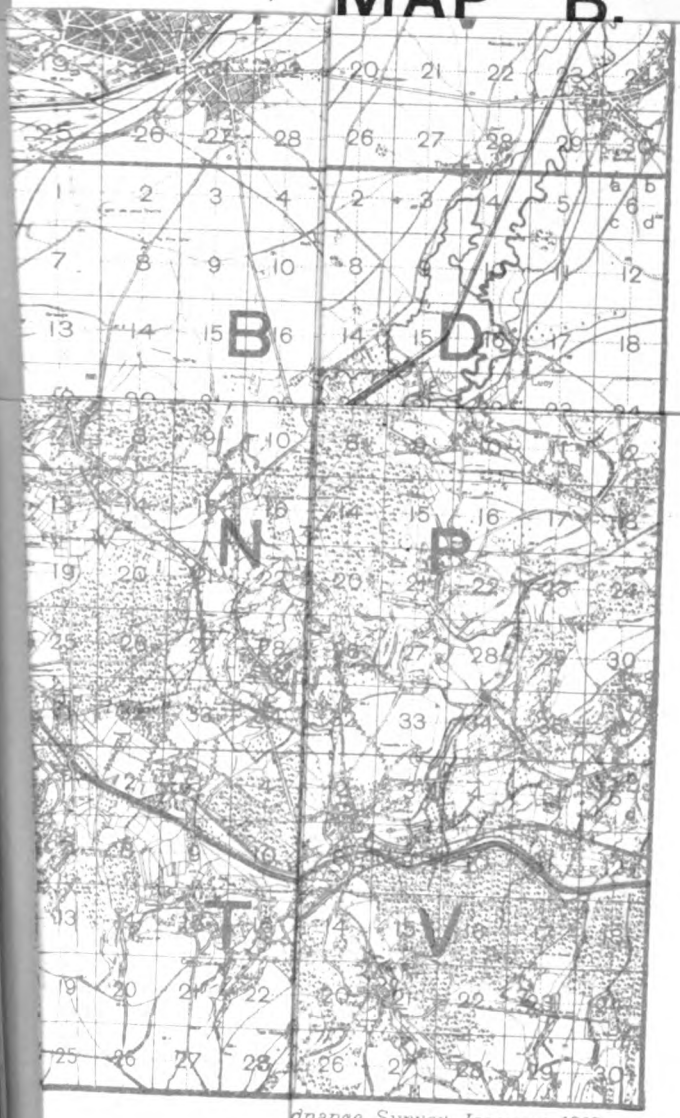
MAP "B."



dnance Survey, January 1918.

15 Miles

20 Kilometres

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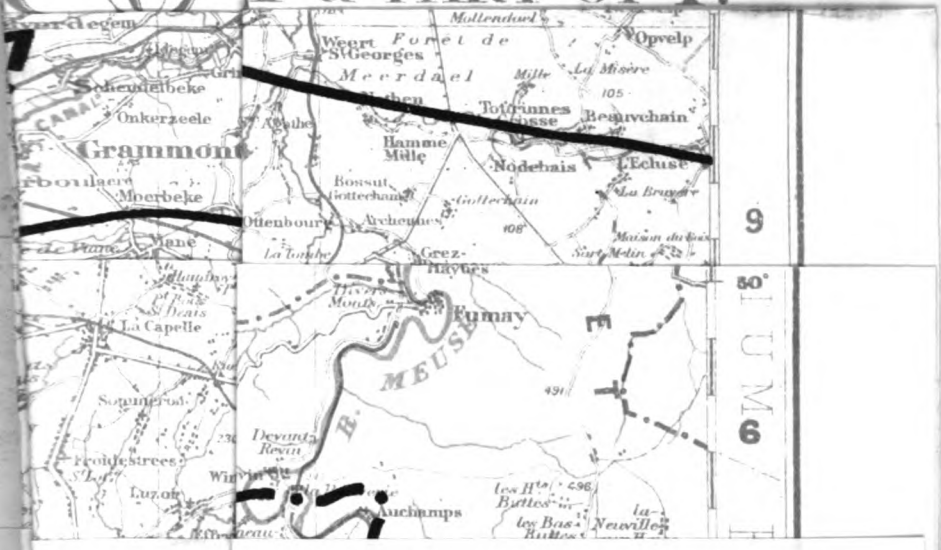

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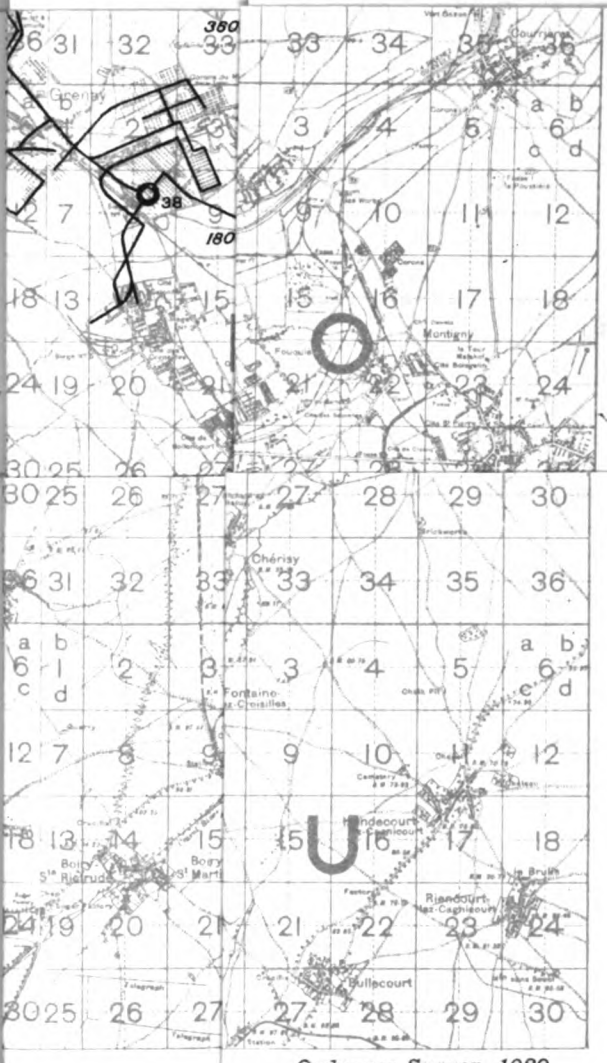

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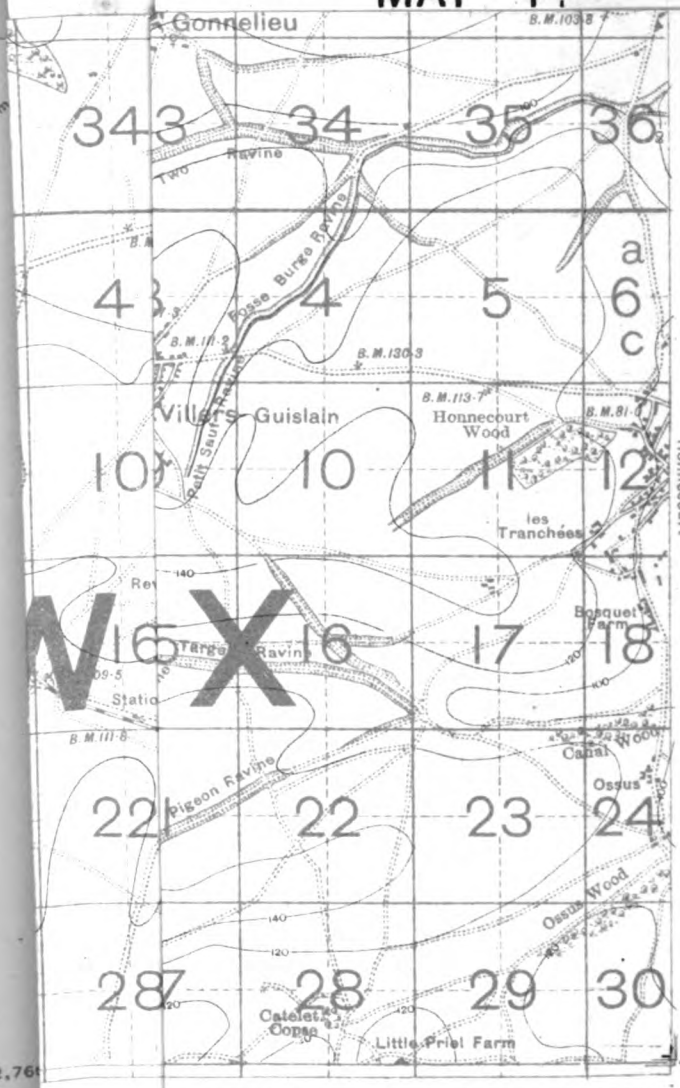

Ordinance Survey, (O.B.) September, 1918.

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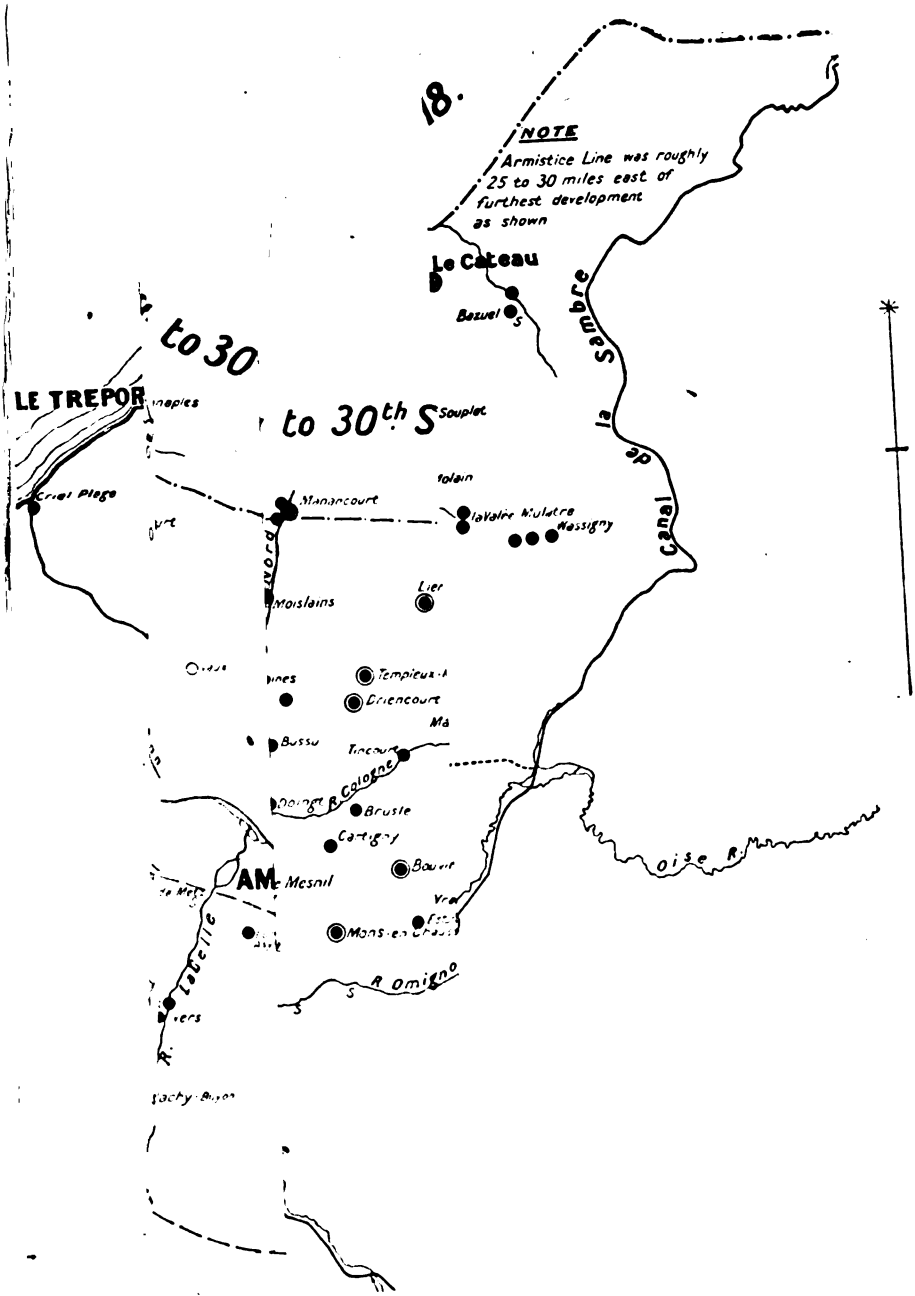
MAP G.

FOU



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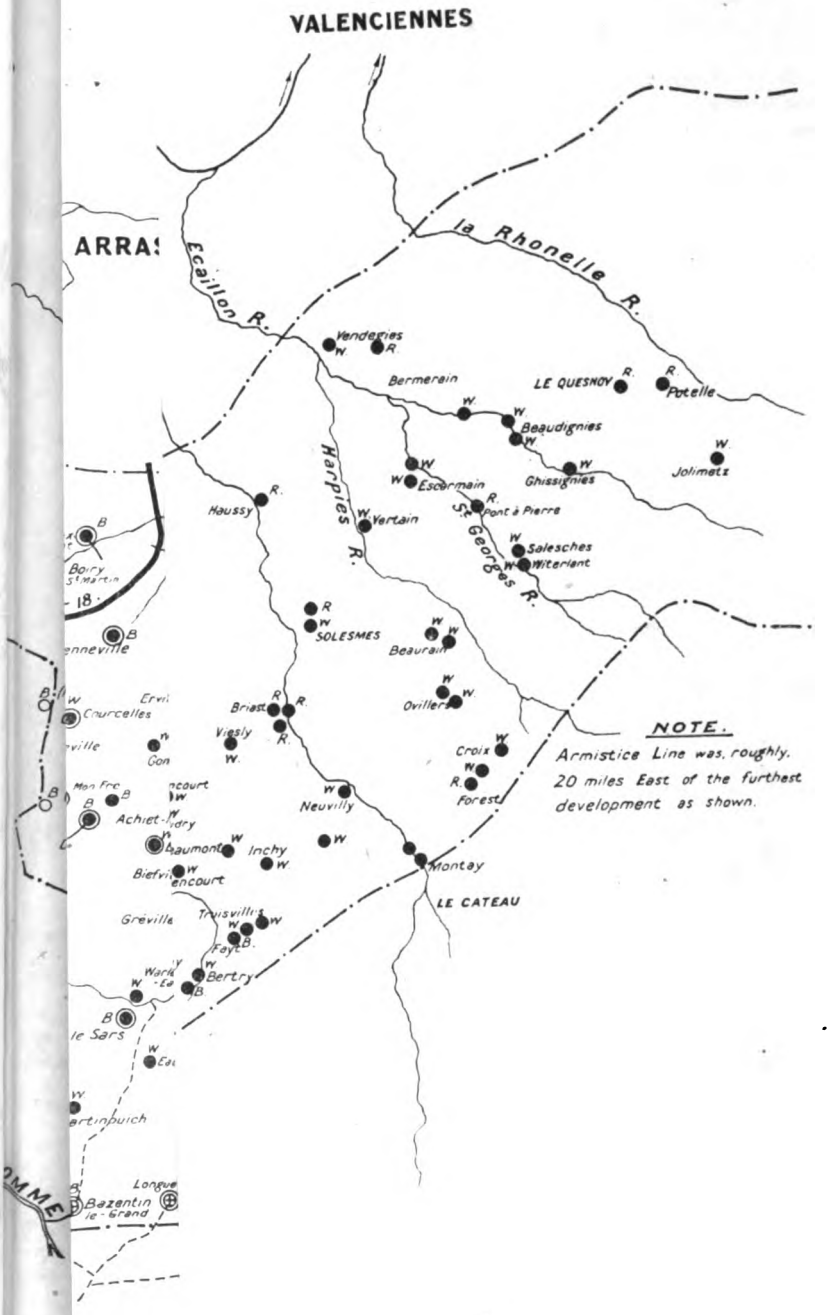
MAP H.



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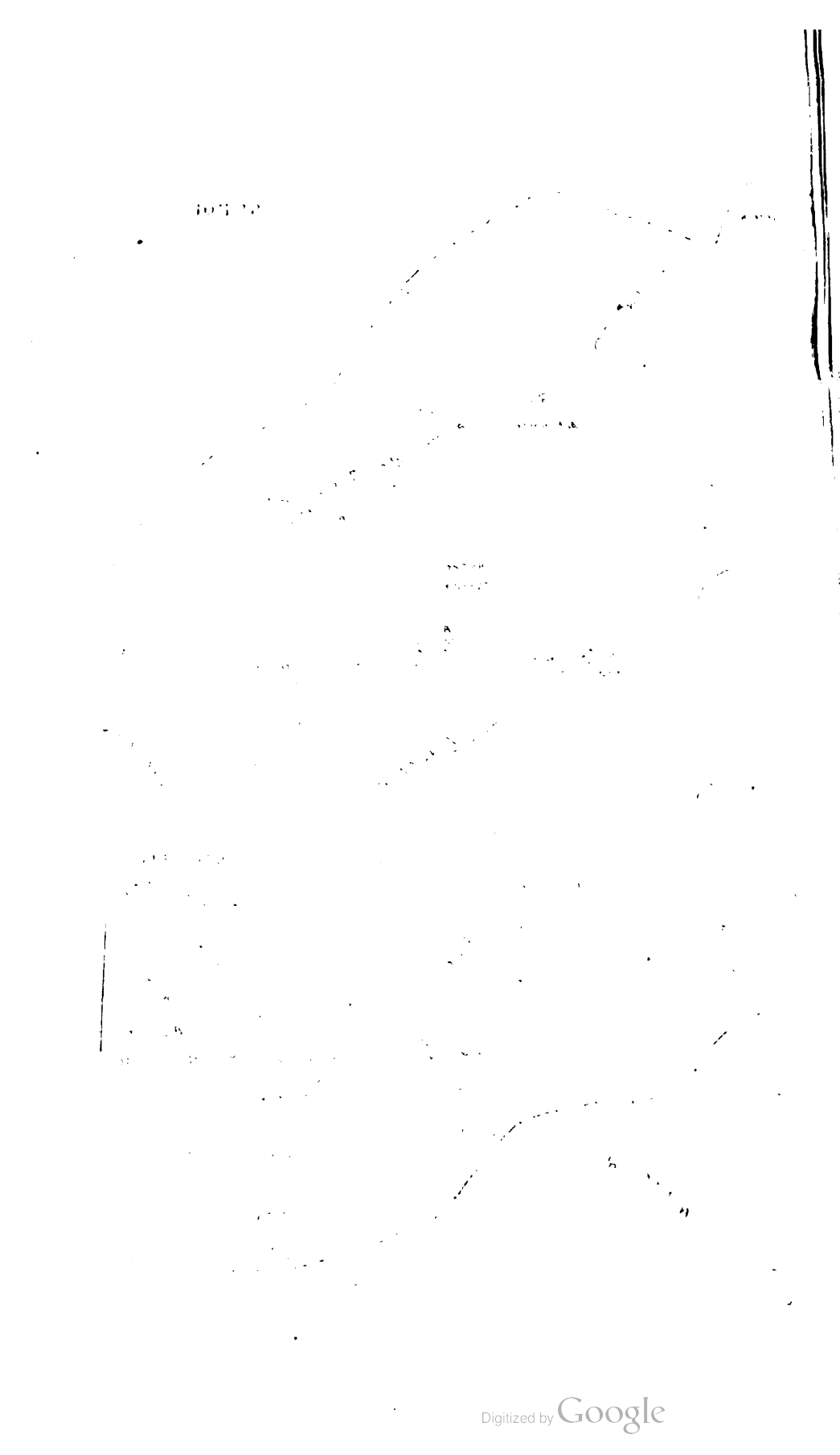
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INDEX.

ACIDIC REACTION, 53
Advance pipe lines, 59
—— pumping stations, 58
Air lift, 41, 69, 73, I. *Plate* IX.
Alum, 17, 52, 76, 77, I. *Plate* XXX.
American W.S. organization, 26, I. *Plate* III.
Ancre, 15
Animals, 48
——scale of supply, 15
Army, British 1st, 73, 81, II. *Map* E
—— —— 2nd, 38, 39, 46, 75, 77, 79, II. *Plates* V., VI.
—— —— 3rd, 16, 19, 20, 22, 44, 57, 67, 70–73, 81, 83, 87, II. *Plate* IV., *Maps* B, H
—— —— 4th, 16, 19, 20–22, 57 *et seq.*, 67–70, 72, 73, 77, 78, 81, 83, 84, 87, II. *Plates* I.—III., *Maps* B. G
—— —— 5th, 67, 69–72, 79, II. *Map* A
—— —— Reserve, 67
—— Boring Sections, 45
—— Control Stations, 76
—— Pumping Stations, 58
—— Supply Columns, 16
—— Troops Cos., R.E., 21, 44
—— Water Columns, 59, 62, 63, 67
—— W.S. officers, 79
Arras, 15, 40, 70, II. *Plate* IV.
—— Town supply, 70, I. *Plate* XI.
Artesian wells, 14, 70
Ashford Strainers, 46, 71, I. *Plate* XVI.
Aster-Berger, 66
Australian E. and M. Co., 23, 45
Aux-Rietz, 74
Aveluy, 73

BALMFORTH, 37
Bapaume plateau, 71
Barastre, 73
Barge purification plants, 16, 60, 65
Barges, seagoing, 78, II. *Plate* VIII.
Bas, 73
Base workshops, 30
Beatthale, 41
Behagnies, 73
Belgium conditions 1914, 14
—— water supply, 27
Bell Bros., 17
Belt pump, 43, I. *Plates* XII., XIII.
Berger, 66
Bergues, 18
Béthune, 14
Birr, 77
Blackstone, 36, I. *Photo* II.
Bleaching powder, 17, 50
Boesinghe, 75–77, II. *Photo* IV.
Boilers, 37
Bollezeele, 77
Boosting station, 76, II. *Photos* II., III.
Bore-holes, 65, 72, 75
Boring, 23
—— plant, 45, 49
—— Sections, 69
—— tools, 46, I. *Plate* XIV.
Brackett, 36
Brady, Major, 27
Branch pipes, 32
Bray, 78
Bridge, w.s., II. *Photos*, XI., XII.
Broome and Wade, 41, I. *Photo* XIII., *Plate* XI.
Brown-Pearn, 66

C.G.S., 14
C.M.E., 34, 36
Caftet Wood, 66
Cambrai, 34, 79, 86
Cameron, 37
Canal-du-Nord, 72, 83
Canvas tank, 48
—— trough, 50
Carnoy, 64, 66, 73
Casualty Clearing Stations, 80
Caterpillar Valley, 82
Cavelier, General, 28
Cave systems, 70
Centralized Control, 67
Centrifugal pumps, 34, 39 *et seq.*, 81
Chaine Helice pump, 42
Chalk, 41, 48
Champagne, 15
Chartiez, M., 27
Cheapside, 77
Chief Engineer, B.E.F., 14, 15, 29
Chief Engineers, 16, 19, 21, 23, 33
Chlorination, 17, 46, 50, 51, 76, I. *Plate* XXVI., XXX.
Chlorinator tables, 53
Coastal area, 77
Cochran, 37, 78
Cojeul R., 83
Collar C.I., 32, I. *Plate* IV.
Compressor lorries, 42, I. *Photos* XII., XIII., *Plates* X., XI., 83, II. *Photo* X.
Compressors, 41, 66
Contractors, 35
Convoys, lorry, 63
Corps W.S. Officers, 19
Coventry Simplex, 41
Cunewele bore, 46, I. *Plate* XV.

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D.D.W., G.H.Q., 14
D.G.M.S., 14
D.G.T., 17
D.I.W.T., 15
Dam, Ypres Canal, 77, II. *Photo* VI.
Dando hand-pump, 63
Day, 40
De Dion, 41, I. *Photo* XIII.
De-poisoning, 15, 62
Deep-well hand-pump, 39
—— —— bore, I. *Plate* XV.
Denain, 87, II. *Photo* XII.
Denis-Gwynne, 66
Denis, 40, 78, I. *Photo* IX.
Depôts, tin filling, 51
Deputy E. in C., 34
Development, summary to July 1916, 20
—— after attack, 64
Diagram of organization, 24
Dickebusch, 75, 79, II. *Plate* IX.
Diesel, 40
Director of Works, 23
Directorate, Engineer stores, 29, 33
Divisional C.R.E.s, 21
Dixon Bros. and Hutchinson, 41
Doornpanne, 78
Dorman, 40, 41, I. *Photos* VIII., XII., *Plate* X.
Douai, 86
Dug-outs, pumps for, 36
Duke and Okenden, 38, 39, 64
Dunkerque, 18, 77, 78, II. *Map* C
Duplex pumps, 37

E. AND M. Companies, R.E., 21, 22, 44, 45, 68, 79
Eau de Javel, 52, I. *Plates* XXVII., XXVIII.
Elverdinghe, 76, II. *Photos* II., III.
Engine power, 44
Engines, 34
Engineer in Chief, 15, 29, 33, 34, 46, 82
Escaut R., 82, 84
Evans, 36

F.W.D. LORRIES, 45
Fargny mill, 66, 82
Farrar, 37
Feed pipes to troughs, 50
Field Companies, R.E., 21
Filters, 46, I. *Photo* XXI.
Filtration, 17, 79, II. *Plate* IX.
Fire engines, 37, 38, 60, 61, 64, 65
Fire pumps, 37
First aid pumping lorries, 62
Fittings, 30, 32
Flanders, 14
Flexala, 40
Flexible pipe, 4 in., 32
Force in Flanders, June 1915, 14
Fort Rompu, 18
Frame, canvas tank, 48, I. *Plate* XVIII.
France, N.E., 14, 27, 68
French well sinkers, 60
Fricourt system, 65
Froissy, 18
Frost, 68
Fuel, 44

GARDNER, 38
Gas shells, 51
Gavrelle, 74, II. *Photo* I.
Gentelles bois, 81
German maps, 83, II. *Map* F
—— offensive, 1918, 80 *et seq.*
—— pumps, 39, 79
—— withdrawal, 1917, 68, 71
Geologist, G.H.Q., 24, 71, 80, 82
Geology, 24, 25, 26, 74, I. *Plates* I., II.
Ginchy, 73
Gommecourt, 57
Gouzeaucourt, 79
Guard to L and F pump, 50
Guillemont plateau, 65, 66
Guy and Mital, 36, I. *Photo* IV.
Gwynne, 40, I. *Photo* X.

HAND PUMPS, 39
Haplincourt, 72, 73
Harenghe, 47, 53, 75, 76, I. *Photos* XX.—XXV., *Plate* XXXII.
Havre store, 44
Hayward, Tyler & Co., 36, 37, 78, I. *Photo* III.
Hazebrouck, 38
Hooge, 76
Hornsby, 41
Horse troughs and standings, 48–50, I. *Plate* XX.
—— watering points, 65, I. *Photo* XVII
—— —— in frost, 69
Huddleston Road, 77

I.R.E.M., 23, 32
I.W.T., 17
Ingersol Rand, 41
Initial water points, 57, 58
Inspector of Mines, 23
Intake, Haringhe, I. *Photo* XXV.
Isler, 38, 45, I. *Photo* XIV.

JESUS FARM, 18
Japy, 36
Joints, sailcloth, 49, I. *Plate* XVIII.

KEIGHLEY, 40, 41, I. *Photo* X.
Kelvin petrol engine, I. *Photo* XXIII.
Keystone drills, 45
King, Lieut. W. B. R., 27

L.C.C. FIRE ENGINES, 37, 38, 60, 61, 64, 65
La Bassée Canal, area S. of, 74
La Panne, 78
La Vacquerie, 79
La Vicogne, 83, II. *Photo* X.
Laboratories, 17
Lacy-Hulbert, 41, I. *Photo* XII, *Plate* X.
Langemarck, 76
Le Clipon, 78, II. *Plate* VII.
Lids to tanks, 51
Lift and force pump, 50, I. *Plate* XXIII.
Lille, 86
Lime, milk of, 53
Linking up supplies, 72
Lister, 36

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Local supplies, 60
—— water points, 50
London Electrical Engineers, 22
Lorries, 3-ton, 16, 20, 41, 42, 48, 62, 63, 67, 78, 82, I. *Plate* XI., XVII.
Lorry stand pipes, 48, 50
Luce R., 68
Lumby, 37
Lys Valley, 14, 17, 18

MACHINERY, 33 *et seq.*
Mametz Valley, 82
Manancourt, 72
Manufacturers, 35
Mather-Platt, 40, 47, 78, I. *Photos* VIII., IX.
Matthews, 36
Mechanical filters, 46, I. *Photo* XXI.
Memo : on Advanced Water Supplies, 57
Men, scale of supply, 15
Mercheghem, 77
Mericourt, 66
Merryweather, 37, I. *Photos* V., VI.
Messines, 15, 75, II. *Plate* V.
Mesopotamia, 18, 45
Millain, 77
Mobile Air Compressors, 42, 81
—— Pumping Sets, 59, 61
Montauban, 65, 66
Motor water tanks, 16
Multi-stage pump, 40

NEUVILLE, 87, II. *Photo* XI.
Nieuport, 18, 77, 78
—— Furnes Canal, 18
Noordhofwijk, 77
Norton Tube well, 77, 78
Notice boards, pipe line, 32, I. *Plate* VI.

OFF LOADING WATER TRANSPORT, 63
Oost Dunkerque, 78
Operations, 57 *et seq.*
Ordnance stores, 29
Organization, 13 *et seq.*
—— diagram, 24
Oswald Stott, 40

PALESTINE, 45, 71
Parks, R.E., 21, 29, 30
Passchendaele, 76, 77, II. *Plate* VI.
Pearn, 36, 66, I. *Photo* I.
Pelapone, 40, 41
Peronne, 18
Petrol consumption, 83
Petters, 36, 41, I. *Plate* XII.
Pipe laying, 81, II. *Photo* IX.
—— tools, 29
Piping, 29
Poison, 17
Police, 49
Poste de Javellisation, I. *Plate* XXVII.
Potter & Warner, 38, I. *Photo* VII.
Power driven pumps, 20, 70
Pozières, 73
Pre-sedimentation, 76
Pulsometer, 40
Pumps, 34
Purification, 15, 16, 52

Q.M.G., 14, 17, 33, 82
Querrieu, 68
Quick-joint, 30

R.A.M.C., 19
R.A.S.C., 19
Rail, canvas trough, 50
Railway, light, 77, II. *Photo* V.
Ram pump, 34, 35 *et seq.*
Ransome Ver Mehr, 17
Registration, machinery, 45
Reserve of pumps, 61
Reservoirs, 48, I. *Plate* XIX.
Rocquigny, 73
Roosendael, 78
Roto-plunge pumps, 41, I. *Photo* XI.
Rousbrugge, 18
Running contracts, 35

ST. QUENTIN CANAL, 84
St. Sauveur, 70
Sailcloth, 49
Salonika, 45
Sand, 39, 41
—— dunes, 78
—— filters, 76
Sapignies, 71, 73
Scales of supply, 1915, 15
Schipstadt, 77
Sedimentation, 17, 52, 76, I. *Photo* XXII., II. *Photos* VII., VIII.
Sensée R., 83
Service des Eaux, 36
Settling tanks, 51
Shanks, 36
Sinking pumps, 37
Somme, 15, 18, 21, 23, 34, 57 *et seq.*, 73, II. *Plates* I., II., III.
Souchez Valley, 74
Spare engines and parts, 43, 44
Special stores, 29, 31
Speed rates, lorries, 63
Spencer, 37
Springs, 50, 72
Standardization, machinery types, 34
Stanier, Prof., 27
Star drills, 45, I. *Photos* XV., XVI.
Steam pumps, 37
Steenbeek, 77
Sterilizing lorries, 46, 62
Storage, 15, 51
—— reservoirs, 48
Stores, 29 *et seq.*
Strahan, Dr., 27
Strainers, tube well, 46
Suzanne system, 64, 65
System of work, 21

TALUS BOISÉ, 64
Tangye, 36, 37, 39
Tangyro, 70
Tank lorries, 64
Tanks, 32, 49, 61, I. *Plates* VII., XVIII
Tarpaulins, 29, 48, I. *Plate* XVII.
Tarring sailcloth, 49
Thames lighters, 78
Thanet sands, 41, 77, I. *Map* B
Thorneycroft, 41

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Tins, 2-gal., 51
Tools, well boring, I. *Plate* XIV.
Transport, 62
Transportation Directorate, 17
Trench filling points, 51, I. *Plates* XXIV., XXV.
—— pumps, 40
—— supply, 57
Trones Wood, 66, 73
Troughs, 49, 50
Tube well pumps, 38
Tunnel mouth, 72
Tyne Electrical Engineers, 22

UNITED WATER SOFTENER, 47

VALIANT PUMP, 37, I. *Photos* V., VI.
Van der Scheuren, M., 27
Vauban, 70
Velu, 73
Villers Brettoneux, 81
Vimy Ridge, 73
Volherinckhove, 77

WAGON, G.S., 82
Wallace & Tiernan apparatus, 19, 46
War Office, 15, 16, 19, 20, 22, 33, 34
Water Boring Sections, R.E., 23, 79
—— barges, 59, 60
Water bottle fillers, 32, 48, 50, I. *Photo* XVIII., *Plates* V., XXVI.
—— cart stand pipe, 48, 50
—— —— filling point, I. *Plate* XXI.
—— carts, 15, 16, 20, 59, 63, 64
—— column, 59, 62, 63, 67
—— discipline, 49
—— lifts, 42
—— points, 48, I. *Photo* XIX., *Plate* XXII., II. *Photos* IV., V.
—— Supply Committee, 14 *et seq.*, 57
—— —— officers, 19, 21, 30, 32, 34, 39, 49, 79, 83, 86
Watts, Prof., 27
Well boring tools, I. *Plate* XIV.
Well sinkers, French, 60
Well windlasses, 39, I. *Plate* VIII.
Wells, 64, 76–78
Wells destroyed, 71
Wieltje, 76
Wilton, 40
Works, 48 *et seq.*
Worthington, 37

YPRES, 14, 40, 75–77, 79, II. *Plates* VI., IX., *Photos* VI., VII., VIII.
Yser, 18, 75, 77–79, II. *Map* C

ZILLEBEKE, 75–77, 79

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